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Permafrost and Terrain Research and monitoring: Norman Wells Pipeline

Volume 1
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Northern Affairs Program

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Norman Wells Pipeline crossing of Canyon Creek, 19 km south of Norman Wells. Norman Wells and the Mackenzie River are located in the upper center and left, respectively. The slope in the foreground is partially insulated with wood chips below the sandbag erosion control berms; the slope in the background is fully insulated and also instrumented for monitoring.

FOREWORD

This report on the Permafrost and Terrain Research and Monitoring Program along the Norman Wells Pipeline has been divided into two volumes. The first volume sets the stage by reviewing environmental and engineering considerations, and aspects of pipeline construction and operation. The second volume presents results from 1983 to 1988. Most important, the second volume contains conclusions and recommendations. The Executive Summary covers the contents of both volumes, as does the list of references. Abbreviations of names and technical terms and glossaries of permafrost and pipeline related terms also appear in both volumes.

For readers wanting more background on the instrumented monitoring sites along the pipeline, this information is contained in a site establishment report (Pilon et al., 1989) published as Geological Survey of Canada (Department of Energy, Mines and Resources) Open File 2044. Thermal data are available in a series of annual reports from the Geological Survey of Canada (Burgess, 1986 and 1987; Burgess and Naufal, 1989 and in prep.: Open Files 86-6, 1621, 1987). A complete listing of reports and papers based on the Permafrost and Terrain Research and Monitoring Program is given in the appendix of each volume.

Copies of this Environmental Studies report (Volumes I and II) are available, without charge, by writing:

Public Enquiries and Response Division
Indian and Northern Affairs Canada
Ottawa, Ontario, K1A 0H4

Please quote the complete title and departmental "QS" catalogue number (Permafrost and Terrain Research and Monitoring: Norman Wells Pipeline. Volume I - Environmental and Engineering Considerations. Volume II - Research and Monitoring Results: 1983-1988.)

The Geological Survey of Canada Open Files are available for viewing at the Resident's Geologist's Office, Yellowknife and can be purchased from the following sales outlet:

Ashley Reproductions Inc.
386 Bank Street
Ottawa, Ontario, K2P 1Y4 Tel: (613) 235-2115

The site establishment report (Open File 2044) is also located in Territorial Government and Indian and Northern Affairs libraries in Yellowknife and the Science Institute's Library at the Inuvik Research Center in Inuvik.

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Many groups and individuals have given us invaluable help during field and office aspects of pipeline research and monitoring from 1983 to present. The scope of monitoring would have been impossible without this encouragement and help.

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EXECUTIVE SUMMARY (Volumes I and II)

The 324 mm (12.7 in) diameter Norman Wells pipeline, owned and operated by Interprovincial Pipe Line (NW) Ltd. (IPL), is the first completely buried oil pipeline in the discontinuous permafrost zone in northern Canada. The 869 km (540 mi) long pipeline from Norman Wells, Northwest Territories to Zama, Alberta is located in thaw-sensitive terrain in a relatively remote part of northern Canada with limited seasonal access. Under a special Environmental Agreement the pipeline project is subject to the "principle of minimum practicable environmental and land use disturbance" for all aspects from planning to abandonment. Permafrost and terrain monitoring was established to evaluate impacts and identify improvements for this and future projects.

Major new approaches to the design and environmental impact mitigation have involved minimizing the length of pipeline in thaw-sensitive terrain, minimizing the energy input from the pipeline to ice-rich terrain (small pipe, initially chilled oil), locating the pipe in previously cleared terrain, retarding or preventing thaw of sensitive slopes (wood chip insulation), increasing the strength of the pipe (pipe grade, wall thickness), and frequent monitoring and rapid response to unstable conditions (drainage and erosion control problems).

Main pipeline construction was completed during the winters of 1983-1984 and 1984-1985. Pipeline operation started in April 1985. The pipeline has a design capacity of 4800 m^3/day (30,000 b/d) and an expected life of 25-30 years. The pipeline is buried at approximately 1 m depth and operates with three pump stations (km 0, km 336 and km 585). Oil movement from Norman Wells has increased from an average of 21,700 b/d in the first year of operation to 26,100 b/d in the third year.

The mechanism for a Permafrost and Terrain Research and Monitoring Program was established under the "Environmental Agreement" signed between IPL and the Minister of Indian and Northern Affairs Canada (INAC). The Company agreed to cooperate with the Minister in the development and implementation of a monitoring program. The monitoring program is designed to "facilitate an evaluation of the impact management process in order to improve on impact evaluation and mitigation on the Norman Wells Pipeline and future projects." Major aspects of the program include 1) examining thermal and terrain conditions at 23 main instrumented sites (e.g. pipe temperature sensors and a series of 5 and 20 m ground temperature cables on and off the right-of-way) over 819 km, 2) regular observations of overall right-of-way conditions, and 3) reviewing the performance of wood chip

insulation used on thaw-sensitive slopes. Monitoring is planned for 5-10 years or until conditions stabilize.

The experience, observations and data bases available from the Permafrost and Terrain Research and Monitoring program are unique: similar data bases on an operational pipeline are not publicly available for any other northern pipeline project in permafrost in North America or other circumpolar areas. The Program is also unique in being the first Canadian environmental monitoring program to address the issue of northern climate change in relation to environmental protection on a specific northern engineering project.

In terms of overall pipeline and environmental performance in N.W.T. through 1988, 1) there have been no pipeline breaks and few pipeline exposures and 2) effects extending beyond the right-of-way (ROW) have been localised and short term, primarily as a consequence of prompt IPL remedial action. Tension cracks and settlement on insulated slopes are regularly investigated. Since operations, two pipeline water crossings have been rebuilt (Hodgson Creek and Ochre River) and the pipe has been reburied in one floodplain (Hodgson Creek).

Volume I of this report summarizes environmental and engineering considerations related to Norman Wells pipeline design, construction and operation. Volume II presents results and recommendations based on observations and data obtained during construction and the first three to four years of operation. The results focus on the pipe temperature and ground temperature conditions, thaw depths, surface settlement, climate conditions, terrain performance, and thermal performance of wood chip insulated slopes. Some conclusions must be considered preliminary because of the short operational time of the pipeline and the variable time lag involved in detection of ground thermal and other changes, especially since the response of critical ice-rich permafrost terrain is slow.

CLIMATE

Climate data used in pipeline and mitigation design were based primarily on the records of two meteorological stations with more or less full records from 1951-1980 and two stations with incomplete records. These stations near the Mackenzie River only partially reflect diverse conditions along the pipeline corridor.

Climatic conditions, especially air temperature, winter snowcover, spring runoff and summer precipitation have played an important role in determining the terrain response to disturbance during the period 1983-1988. The climatic conditions are only partially known due to the limited meteorological data collection

along the pipeline route: summer precipitation records have been significantly enhanced with the data obtained at Forestry stations near the pipeline since 1982.

Two major flood events have affected the Hodgson Creek crossing (km 305), in June 1986 and July 1988. In both cases, rainfall recorded at the nearby Mount Gaudet Forestry station reached or exceeded the estimated 100-year maximum 24-hour precipitation level. The July 1988 flood also eroded the river bank at Ochre River, exposing 20-30 m of pipeline which was undetected due to high silty water for about 2-3 weeks following the storm.

There is some evidence of a systematic climatic warming trend at Norman Wells and Fort Simpson, specifically warmer air temperatures over the last 40 years. Climate change, a concern raised in the environmental review of the project, was not specifically taken into consideration in the Norman Wells pipeline detailed thermal design (e.g. thaw depths, thaw settlement). IPL felt it could be addressed in terms of remedial response during operation.

PIPE AND GROUND TEMPERATURES

The pipe thermal regime follows an annual variation similar to that of the ground thermal regime (with the exception of the site adjacent to the Norman Wells pump station). At a particular point in time pipe temperature readings do however differ by more than 3-5 degrees from an adjacent ground temperature reading taken at a similar depth.

The short term thermal behaviour of the Norman Wells pipeline is that of a warm line, i.e. mean annual temperatures between 0°C and 5°C, both through the widespread discontinuous permafrost terrain in the northern part of the route (north of Wrigley) and the sporadic discontinuous permafrost terrain in the south. With the exception of warm (>2°C) winter pipe temperatures recorded at monitoring sites within 23 km downstream from Pump Station 3, observed pipe temperatures (monthly data) have been within the range of predicted values used in the detailed thermal design. An increase in pipe temperatures of 2-3 degrees occurs across Pump Station 3.

In general (18 of 23 instrumented sites between km 0 and 819) mean annual pipe temperatures increased during the first two years of pipeline operation, on average by 1 degree. This corresponds with an operations scenario of increased flow rate and increased chilling.

The warm mean annual pipe thermal regime (>0°C) indicates that frost heave due to development of a permanent frost bulb around the pipe is not of concern except near the chilled input.

Although the terrain and ground thermal regime may differ substantially between adjacent monitoring sites (within 1 km of each other), the pipe thermal regime remains the same. The distance required for the pipe to come into equilibrium with surrounding terrain is much greater than the scale of spatial variation in the ground thermal regime. In other words the pipe temperatures do not respond to short lengths of ground temperature change and either cool or warm the surrounding ground.

Mean annual pipe temperatures are generally warmer (on average by 1.5 degree) than mean annual ground temperatures on the ROW outside the trench area at a depth similar to that of initial pipeline burial (approximately 1 m) both in old and newly cleared right-of-way. Mean annual ground temperatures on-ROW are generally warmer than those off-ROW (by 1 degree on average). The warmer pipe temperatures are likely a combination of pipe effects and the more disturbed conditions in the trench as compared to the rest of the ROW.

The ground temperatures on the ROW also showed a general warming trend and continue to warm. The thermal response of ice-rich soils and thick frozen organic terrain is particularly slow due to freeze and thaw of pore water.

ACTIVE LAYERS AND THAW DEPTHS

The 30 year design thaw depth predictions varied from 6.1 to 12.2 m depending on terrain type and pipeline segment. Active layers, defined here by the maximum depth of penetration of the 0°C isotherm and measured by the ground temperature cables, ranged from <0.5 to <3.0 m on the ROW at the end of the 1987 thaw season. Active layers off-ROW by comparison were generally <1m. These observations are within the 30 year design thaw depth predictions; however short term thaw depth predictions have been reached at several sites and exceeded at one. By the fall of 1987, active layers on-ROW had increased by up to 1 m, while off-ROW they generally stayed the same.

SURFACE SETTLEMENT

Surface settlement affects surface drainage, ponding and erosion, and may be used as an indicator of possible pipe settlement (a pipe settlement monitoring program is undertaken separately by IPL).

For the ROW, excluding the pipe trench area, maximum recorded settlements of 50 cm or more have been observed at 6 sites. In the trench area, where settlement included thaw of frozen uncompacted backfill, the maximum recorded settlement to the end of the 1987 thaw season had reached 50 cm or more at 13 of the 23 instrumented sites, with 3 sites showing a maximum of 100 cm or more. Most of these sites have a depression in the ditch area below the level of the surrounding ground surface ("subsided ditchline").

Right-of-way surface settlement is ongoing. For the non-trench portion of the ROW localized areas of surface settlement in excess of the detailed design predictions have been observed at 4 sites. In the trench area surface settlement in excess of the design predictions has been recorded in localized pockets at 9 permafrost monitoring sites.

IPL has increased their pipe settlement monitoring since fall 1986 including the development of an "inertial monitoring pig" for the detection of differential pipe settlement and other pipe conditions.

WOOD CHIP INSULATION

An insulating cover of wood chips up to 1.8 m thick was placed on 55 thaw-sensitive slopes. The wood chips have exhibited internal heating as a result of microbial decomposition during the first summer period after placement. Except for about 6 slopes the warm temperatures (16 to 40°C) built up in the wood chip layers were dissipated with the coming of the cold fall air temperatures. Early snow cover provided an insulating layer which may have prevented heat removal from the other slopes. Some reheating occurred in most wood chip layers during the second summer period, but usually to a lesser extent.

The heating of some wood chip covered slopes, which were instrumented, has indicated thaw in excess of the 25-year predicted thaw. The evidence from snow melt patterns suggests that heating occurs in pockets within the wood chip layer and is not extensive on the slope.

Snow accumulation on the wood chip insulation, along with the conditions mentioned above, have combined to cause an increase in the mean annual ground temperature. This appears to be gradually thawing the soil beneath the wood chip layer. The influence of this thaw is more extensive throughout the wood chip covered slope surface than the localized microbial heating phenomenon.

TERRAIN PERFORMANCE

The most pronounced effect of construction disturbance on terrain has been the widespread subsidence of material along the ditchline. Ditch subsidence has presented a persistent erosion and maintenance problem but has been reduced through IPL's replacement of select backfill in the ditchline. IPL estimated, based upon interpretation of air photographs taken in July 1986, that approximately 30% of the ditch was visibly subsided. As general ROW surface subsidence continues there will be an increasing tendency for drainage to become channelled along the ROW and especially in the subsided ditch, both of which will be at lower levels than surrounding terrain.

In most cases erosion structures have performed well in limiting surface erosion of the ROW. However, numerous examples of small-scale erosion (gullying less than 10 cm deep) have occurred, frequently initiated by intense summer rain storms. A smaller number of erosion events have resulted in gullying to depths ranging from 20 cm to 3-4 m, in some cases resulting in loss of ditch backfill and exposure of the pipe. There has also been complete or partial failure of drainage control structures (e.g. Great Bear River north slope, Blackwater River north slope). Erosion has also occurred in areas where no drainage control structures were included in the original design (e.g. south side of Norman Range).

At several water crossings erosion, and associated disturbance of mitigation structures, has occurred due to high water events (e.g. Hodgson Creek, Ochre River and others) and, in some cases, insufficient streambank protection (e.g. Canyon Creek, Heleva Creek and others). Major floods affecting Hodgson Creek (1986, 1988) and Ochre River (1988) pipeline crossings have illustrated the difficulty in predicting hydrologic regimes within the Mackenzie Valley, and argue for a more conservative approach to flood estimation.

IMPROVEMENTS

Improvements made in mitigation through fall 1988 as a consequence of discussions and review of observations and data from the Permafrost and Terrain Research and Monitoring Program and the Company's own monitoring program include: 1) changes related to operating oil temperatures, 2) review of data and initiation of remedial activity related to wood chip insulation of thaw-sensitive slopes, 3) review of rate of thaw settlement and use of surface changes to indicate when thaw settlement might be affecting conditions below the pipe, 4) more timely exchange of summer precipitation data from storm events in remote locations along the pipeline, and 5) remedial measures implemented by IPL as a result

of notification from observers on the Research and Monitoring Program.

Improvements made in impact evaluation include: 1) refining parameters examined, 2) testing and utilizing various automatic and manual recording and handling systems, and 3) evaluating frequency and timing of monitoring measurements.

RECOMMENDATIONS

A total of 38 recommendations are given. The majority of the these involve improvements to impact mitigation and environmental protection related to project planning, operations and maintenance. Numerous recommendations emphasize the need for continued data collection, especially to evaluate mitigation in ice-rich permafrost and the potential effects of climate change (temperature and precipitation). The following are some of the major recommendations.

1. It is recommended that INAC continue permafrost and terrain research and monitoring until conditions stabilize (e.g. little evidence of erosion and settlement, or slope, stream bank and thermal instability), or until it is felt that no further practical lessons leading to improvements on the Norman Wells Pipeline or future projects are likely to be learned.

2. It is recommended that government and industry implement cooperative research and monitoring programs on other northern projects in permafrost terrain, where evaluation might lead to improvements in mitigation, and improve on the capability to anticipate environmental problems.

3. To assist in both the planning and safe operation of future pipelines and the continued maintenance of the Norman Wells pipeline, increased attention should be focused upon the implications of climate change. Emphasis should be placed upon analysis of climatic trends and variability, as well as on mean conditions. Rapid climatic change may limit the validity of using 30-year normals values as inputs in geotechnical and geothermal models and environmental protection plans.

4. It is recommended that observations address 1) the complexities and mechanisms of pipe-ground heat exchange (particularly in wet trench conditions where water movement and hence convective heat transfer may occur), and 2) the effects of changes in the pipe thermal regime on the thermal performance, and hence stability of insulated thaw-sensitive slopes.

5. It is recommended that the use of wood chips to reduce thaw of permafrost on future projects consider methods to: 1) keep the wood chips dry throughout the year, and 2) restrict air entering the wood chip layer.

6. It is recommended that water crossings be designed for a maximum flood based on geological/geomorphic evidence, hydrological models, and considerations based on climate change scenarios.

7. It is recommended that the ROW be monitored and maintained frequently (weekly or more often for this and future northern pipelines, especially during the first few years following construction), particularly after spring snowmelt runoff and major summer storm events. Possible misplacement of berms, omission of watercourses from the design, and reduced vegetation cover renders the ROW surface particularly vulnerable to erosion during this period.

RÉSUMÉ (volumes I et II)

Le pipeline de Norman Wells dont le diamètre est de 324 mm (12,7 po) appartient à la société Interprovincial Pipeline (NW) Ltd. (IPL) qui en assure l'exploitation; dans la zone de pergélisol discontinu du Nord canadien, il s'agit du premier oléoduc entièrement enfoui. Le pipeline de 869 km (540 mi) de longueur à partir de Norman Wells (Territoires du Nord-Ouest) jusqu'à Zama (Alberta) est situé en terrain sensible au dégel dans une région relativement isolée du Nord canadien à laquelle l'accès est limité à certaines périodes de l'année. En vertu d'une entente spéciale sur l'environnement, le projet de pipeline est soumis au "principe de perturbation minimale possible de l'environnement et de l'utilisation du terrain" pour tous les aspects qui vont de la planification du projet à l'abandon des lieux. L'observation du pergélisol et du terrain a été entreprise afin d'évaluer les impacts et d'identifier les améliorations dans ce projet et les autres à venir.

Les principales nouvelles approches à la conception du pipeline et à l'atténuation de l'impact sur l'environnement ont consisté à minimiser la longueur du pipeline en terrain sensible au dégel, à minimiser le transfert d'énergie du pipeline au terrain à haute teneur en glace (petite conduite, pétrole initialement refroidi), à situer la conduite dans des terrains antérieurement dégagés, à retarder ou à empêcher le dégel des talus sensibles (isolation aux copeaux de bois), à augmenter la résistance de la conduite (qualité de la conduite, épaisseur de la paroi), à observer fréquemment et à réagir rapidement aux conditions instables (problèmes de drainage et lutte contre l'érosion).

La construction principale du pipeline a été terminée au cours des hivers 1983-1984 et 1984-1985. L'exploitation du pipeline a commencé en avril 1985. Le pipeline possède un débit d'apport maximal de 4800 m^3/jour (30 000 b/j) et une durée de vie prévue de 25-30 ans. Le pipeline est enfoui à une profondeur d'environ 1 m et est exploité à l'aide de trois stations de pompage (km 0, km 336 et km 585). L'acheminement du pétrole à partir de Norman Wells est passé d'une moyenne de 21 700 b/j au cours de la première année d'exploitation à 26 100 b/j la troisième année.

Le mécanisme de création d'un programme de recherche et d'observation du pergélisol et du terrain a été établi dans le cadre de l'entente sur l'environnement signée entre IPL et le ministre des Affaires indiennes et du Nord Canada (MAINC). La société a convenu de collaborer avec le ministre pour l'élaboration et la mise en oeuvre d'un programme d'observation. Ce programme est conçu pour "faciliter l'évaluation du processus de gestion des impacts afin d'améliorer l'évaluation et l'atténuation des impacts sur l'oléoduc de Norman Wells et les projets à venir". Les

principaux aspects du programme sont les suivants : 1) examen des conditions thermiques et de terrain sur 23 principaux sites munis d'appareils de mesure (p. ex. capteurs de température de la conduite et une série de câbles de 5 et 20 m de longueur pour mesurer la température du sol tantôt sur le droit de passage, tantôt en dehors de celui-ci) sur une distance de 819 km, 2) observations régulières des conditions générales du droit de passage et 3) examen du comportement de l'isolation aux copeaux de bois employée sur les talus sensibles au dégel. L'observation est planifiée sur une période de 5-10 ans ou jusqu'à ce que les conditions se stabilisent.

L'expérience, les observations et les bases de données accessibles grâce au programme d'observation et de recherche sur le pergélisol et le terrain sont uniques : des bases de données semblables sur un pipeline en service ne sont pas accessibles au public, pour n'importe quel autre projet de pipeline nordique en milieu pergélisolé d'Amérique du Nord ou dans toute autre région circumpolaire. Le programme est aussi unique en ce qu'il est le premier programme canadien d'observation de l'environnement à porter sur le problème de changement climatique nordique en relation avec la protection de l'environnement sur un projet spécifique d'ingénierie nordique.

Du point de vue du comportement général du pipeline et de l'environnement dans les T.N.-O. de 1983 à 1988, 1) il n'y a eu aucune rupture de pipeline et seulement quelques sections de pipeline se sont retrouvées exposées, et 2) les effets produits au-delà du droit de passage ont été localisés et corrigés dans de courts délais, principalement par suite d'une action rapide d'IPL. Les fissures dues à la contrainte et le tassement sur les talus isolés font l'objet d'études régulières. Depuis le début de l'exploitation, deux traverses de pipeline au fond de l'eau ont été reconstruites (ruisseau Hodgson et rivière Ochre) et la conduite a été réenfouie dans une plaine d'inondation (ruisseau Hodgson).

Le volume I du présent rapport dresse un bilan des considérations environnementales et techniques liées à la conception du pipeline de Norman Wells, ainsi qu'à sa construction et à son exploitation. Le volume II présente les résultats et les recommandations basées sur les observations et les données obtenues pendant la construction ainsi que pendant les trois ou quatre premières années d'exploitation. Les résultats portent essentiellement sur les conditions thermiques de la conduite et du sol, sur les profondeurs de dégel, sur le tassement en surface, sur les conditions climatiques, sur le comportement du terrain et le comportement thermique des talus isolés aux copeaux de bois. Certaines conclusions doivent être envisagées au préalable en raison de la courte période d'exploitation du pipeline et du retard variable accusé dans la détection des changements thermiques du sol et autres, spécialement parce que lente est la réaction du terrain pergélisolé à haute teneur en glace.

CLIMAT

Les données climatiques employées dans la conception du pipeline et de l'atténuation de l'impact sur l'environnement ont été basées principalement sur les archives de deux stations météorologiques possédant des archives plus ou moins complètes pour la période 1951-1980 ainsi que de deux stations dont les archives sont incomplètes. Ces stations situées près du fleuve Mackenzie ne reflètent que partiellement les diverses conditions qui règnent dans le corridor du pipeline.

Les conditions climatiques, spécialement la température de l'air, le manteau nival d'hiver, le ruissellement printanier et les précipitations estivales ont joué un rôle important dans la détermination de la réaction du terrain aux perturbations pendant la période 1983-1988. Les conditions climatiques ne sont connues que partiellement parce que la collecte des données météorologiques est limitée le long du tracé du pipeline : les enregistrements de précipitations estivales ont été sensiblement rehaussés avec les données obtenues auprès des stations de foresterie situées à proximité du pipeline depuis 1982.

Deux grandes inondations ont affecté la traverse du ruisseau Hodgson (km 305), en juin 1986 et en juillet 1988. Dans les deux cas, les pluies enregistrées à la station forestière voisine de Mount Gaudet ont atteint ou dépassé le niveau de précipitation maximal de 24 heures estimé sur une période de 100 ans. L'inondation de juillet 1988 a aussi érodé la rive sud de la rivière Ochre, exposant 20-30 m de pipeline, ce qui est passé inaperçu en raison de la forte turbidité de l'eau pendant les 2 ou 3 semaines qui ont suivi la tempête.

Il existe quelques preuves de tendance à un réchauffement systématique du climat à Norman Wells et à Fort Simpson, la température de l'air s'étant particulièrement réchauffée au cours des 40 dernières années. Le changement climatique, un facteur soulevé dans l'examen environnemental du projet, n'a pas été spécifiquement pris en compte dans la conception thermique détaillée du pipeline de Norman Wells (p. ex. profondeurs de dégel, tassement dû au dégel). IPL a estimé qu'elle pouvait aborder cette question en appliquant des mesures correctives au cours de l'exploitation.

TEMPÉRATURE DE LA CONDUITE ET DU SOL

Le régime thermique de la conduite obéit à une variation annuelle analogue à celle du régime thermique du sol (à l'exception du site adjacent à la station de pompage de Norman Wells). À un moment donné, les lectures de température de la conduite diffèrent

toutefois de plus de 3 à 5 degrés d'une lecture de température du sol prise dans le voisinage à une profondeur comparable.

Le comportement thermique à court terme du pipeline de Norman Wells est celui d'un oléoduc chaud (c'est-à-dire des températures annuelles moyennes supérieures à 0°C et entre 0°C et 5°C), tout au long de son traject à travers le terrain à pergélisol discontinu répandu dans la partie nord du tracé (au nord de Wrigley) ainsi qu'à travers le pergélisol discontinu sporadique dans le sud. À l'exception des chaudes températures (> 2°C) de conduite enregistrées dans les sites d'observation situés dans un rayon de 23 km en aval de la station de pompage n° 3, les températures de conduite observées (données mensuelles) se sont situées à l'intérieur de l'intervalle des valeurs prédites employées dans la conception thermique détaillée. Une augmentation des températures de conduite de 2 ou 3 degrés se produit à travers la station de pompage n° 3.

De manière générale (18 des 23 sites munis d'appareils entre les km 0 et 819), les températures de conduite annuelles moyennes ont augmenté pendant les deux premières années d'exploitation du pipeline, en moyenne de 1 degré. Cela correspond à un scénario d'exploitation à débit accru et à refroidissement accru.

Le régime thermique annuel moyen chaud des conduites (> 0°C) indique que le soulèvement dû au gel dû à la formation d'un bulbe de gel permanent autour de la conduite n'est pas inquiétant sauf à proximité de l'apport refroidi.

Bien que le terrain et le régime thermique du sol puissent différés considérablement entre des sites d'observation voisins (à moins de 1 km l'un de l'autre), le régime thermique de la conduite reste le même. La distance requise pour que la conduite viennent en équilibre avec le terrain avoisinant est beaucoup plus grande que l'échelle de variation spatiale qui existe dans le régime thermique du sol. En d'autres mots, les températures de conduite ne réagissent pas aux courtes étendues de terrain avec un changement de la température du sol et elles refroidissent ou réchauffent le sol qui les entoure.

Les températures de conduite annuelles moyennes sont généralement plus chaudes (en moyenne de 1,5 degré) que les températures du sol annuelles moyennes sur le droit de passage à l'extérieur de la zone de tranchée à une profondeur comparable à celle de l'enfouissement initial du pipeline (environ 1 m), tant dans un droit de passage anciennement dégagé que dans un droit de passage nouvellement dégagé. Les températures du sol annuelles moyennes sur le droit de passage sont généralement plus chaudes que celles en dehors de celui-ci (de 1 degré en moyenne). Les températures de conduite plus chaudes sont vraisemblablement le résultat d'une combinaison des effets de conduite et des conditions

plus perturbées dans la tranchée comparativement au reste du droit de passage.

Les températures du sol sur le droit de passage ont aussi montré une tendance au réchauffement général et continuent à se réchauffer. La réaction thermique des sols à haute teneur en glace et du terrain organique gelé sur une forte épaisseur est particulièrement lente en raison du gel et du dégel de l'eau interstitielle.

MOLLISOLS ET PROFONDEURS DE DÉGEL

Les prédictions de profondeur de dégel calculées sur 30 ans ont varié de 6,1 à 12,2 m suivant le type de terrain et la zone de construction. Les mollisols, définis ici par la profondeur maximale de pénétration de l'isotherme 0°C et mesurés à l'aide de câbles de température dans le sol, ont oscillé entre < 0,5 à < 3,0 m sur le droit de passage à la fin de la période de dégel de 1987.

À titre de comparaison, les mollisols situés en dehors du droit de passage étaient généralement < 1 m. Ces observations se situent à l'intérieur des prédictions sur la profondeur de dégel calculée sur 30 ans; des profondeurs de dégel prédites à court terme ont toutefois été atteintes dans quelques sites et elles ont été dépassées à un endroit. À l'automne de 1987, les mollisols mesurés sur le droit de passage ont connu des augmentations atteignant 1 m, tandis que ceux mesurés en dehors du droit de passage sont généralement demeurés les mêmes.

TASSEMENT DE SURFACE

Le tassement de surface affecte le drainage, la formation d'étangs et l'érosion en surface, et peut être utilisé comme indicateur d'un affaisement possible de la conduite (un programme d'observation de l'affaisement de la conduite est entrepris séparément par IPL).

Pour le droit de passage, à l'exclusion de la zone de tranchée de la conduite, des tassements ayant enregistré un maximum de 50 cm ou plus ont été observés dans six sites. Dans la zone de tranchée, où le tassement comprenait le dégel du remblai gelé sans compaction, le tassement maximal enregistré à la fin de la période de dégel de 1987 avait atteint 50 cm ou plus dans 13 des 23 sites d'observations, dont trois montrant un maximum de 100 cm ou plus. La plupart de ces sites possèdent une dépression dans la zone de fossé sous le niveau de la surface du sol environnant ("ligne de fossé affaissée").

Le tassement de surface du droit de passage se poursuit. Sur le droit de passage à l'extérieur de la zone de tranchée, des zones localisées de tassement de surface dépassant les valeurs détaillées des prédictions ont été observées dans quatre sites. Dans la zone en tranchée, le tassement de surface dépassant les prédictions calculées a été enregistré dans quelques poches localisées à neuf sites d'observation du pergélisol.

IPL a intensifié son observation de l'affaisement de la conduite depuis l'automne 1986 en y ajoutant la mise au point d'un "furet de surveillance inertielle" pour la détection des mouvements différentiels de la conduite et ainsi que d'autres conditions de la conduite.

ISOLATION AUX COPEAUX DE BOIS

Une couverture isolante faite de copeaux de bois et pouvant atteindre 1,8 m d'épaisseur a été placée sur 55 talus sensibles au dégel. Les copeaux de bois ont montré des signes de chauffage interne par suite de la décomposition microbienne qui s'est produite pendant le premier été après leur mise en place. Sauf dans le cas d'environ six talus, les températures chaudes (16-40 °C) enregistrées dans les couches de copeaux de bois ont été dissipées avec l'arrivée des températures froides de l'air d'automne. Le manteau nival hâtif a fourni une couche isolante ayant pu empêcher le soutirement de chaleur aux autres talus. Un certain réchauffement s'est produit dans la plupart des couches de copeaux de bois pendant le deuxième été, mais habituellement dans une moindre mesure.

Le réchauffement de certains talus recouverts de copeaux de bois et équipés de câbles de température a indiqué un dégel dépassant le dégel prédit sur 25 ans. La configuration de fonte des neiges suggère que le réchauffement se limite à des poches situées à l'intérieur de la couche de copeaux de bois et que ce réchauffement n'est pas extensif sur le talus.

L'accumulation de neige sur la couche isolante de copeaux de bois, de même que les conditions susmentionnées, se sont combinées pour provoquer une hausse de la température annuelle moyenne du sol. Cela semble faire progressivement dégeler le sol situé au-dessous de la couche de copeaux de bois. L'influence de ce dégel est plus poussée à travers la surface du talus recouvert de copeaux de bois que le phénomène de réchauffement microbien localisé.

COMPORTEMENT DU TERRAIN

L'effet le plus marqué de la perturbation due à la construction sur le terrain a été l'affaissement généralisé des matériaux situés le long de la ligne de fossé. L'affaissement du fossé a présenté un problème persistant d'érosion et de maintenance, mais il a été réduit grâce à l'intervention d'IPL qui a placé un remblai choisi dans la ligne de fossé. IPL a estimé, en se basant sur l'interprétation de photographies aériennes prises en juillet 1986, qu'environ 30 % du fossé était visiblement affaissé. Comme l'affaissement général de la surface du droit de passage se poursuit, le drainage aura de plus en plus tendance à se canaliser le long du droit de passage et particulièrement dans le fossé affaissé, puisque tous deux se trouveront à des niveaux plus bas que le terrain avoisinant.

Dans la plupart des cas, les ouvrages de protection contre l'érosion se sont bien comporté en limitant l'érosion de la surface. Souvent à la suite de fortes tempêtes de pluie survenues en été, de nombreux cas d'érosion à petite échelle (ravinement de profondeur inférieure à 10 cm) ont eu lieu. Des cas d'érosion moins nombreux ont produit un ravinement à des profondeurs comprises entre 20 cm et 3-4 m, allant même jusqu'à produire dans certains cas des pertes de remblai du fossé et la mise à nu de la conduite. Il y a aussi eu des cas de rupture complète ou partielle des ouvrages de régularisation du drainage (p. ex. le talus nord de la Grande rivière de l'Ours, le talus nord de la rivière Black Water). L'érosion a aussi affecté des zones où la conception originale avait indiqué que des d'ouvrages de régularisation du drainage n'étaient pas requises (p. ex. côté sud du chaînon Norman).

À plusieurs points de franchissement de cours d'eau, l'érosion et la perturbation connexes des ouvrages de réduction, ont été causées par les hautes eaux (p. ex. ruisseau Hogson, ruisseau Ochre et autres) et, dans certains cas, une protection insuffisante des rives (p. ex. ruisseau Canyon, ruisseau Heleva et autres). Les grandes inondations ayant affecté les traversées du ruisseau Hodgson (1986, 1988) et de la rivière Ochre (1988) ont illustré la difficulté de prédire les régimes hydrologiques dans la vallée du Mackenzie et justifient une approche plus conservatrice en matière d'estimation des crues.

AMÉLIORATIONS

Les améliorations apportées à l'atténuation des impacts sur l'environnement, pendant la période allant de 1983 à l'automne 1988, par suite des discussions et de l'examen des observations et des données provenant du programme d'observation et de recherche

du pergélisol et du terrain ainsi que du programme d'observation exécuté par la société IPL même comprennent ce qui suit : 1) des changements relatifs aux températures du pétrole pendant l'exploitation du pipeline, 2) l'examen des données et l'amorce de mesures correctrices liées à l'isolation aux copeaux de bois des talus sensibles au dégel, 3) l'examen de la vitesse du tassement dû au dégel et le recours à des changements de surface pour indiquer les moments où le tassement dû au dégel pourrait affecter les conditions régnant sous la conduite, 4) échange opportun des données de précipitation estivale provenant des tempêtes survenues à des endroits isolés le long du pipeline et 5) la mise en oeuvre par IPL de mesures correctrices par suite d'avis exprimés par des observateurs faisant partie du programme de recherche et d'observation.

Les améliorations apportées à l'évaluation des impacts sont les suivantes : 1) le raffinement des paramètres examinés, 2) l'essai et l'utilisation de divers systèmes automatiques et manuels d'enregistrement et de manipulation, et 3) l'évaluation de la fréquence et de la chronicité des mesures effectuées pendant l'observation.

RECOMMANDATIONS

En tout, 38 recommandations ont été faites. La majorité d'entre elles prévoient des améliorations à l'atténuation des impacts et à la protection environnementale relatives à la planification des travaux, à l'exploitation et à la maintenance. De nombreuses recommandations insistent sur la nécessité de collecter des données de façon suivie, particulièrement afin d'évaluer les méthodes d'atténuation dans le terrain pergélisolé à haute teneur en glace et les effets potentiels du changement de climat (température et précipitations). Certaines des principales recommandations sont les suivantes.

1. Il est recommandé que MAINC poursuive les recherches et l'observation du pergélisol et du terrain jusqu'à ce que les conditions se stabilisent (p. ex. rarification des cas d'érosion et de tassement, ou d'instabilité des talus, des rives de cours d'eau, et d'instabilité thermique), ou jusqu'à ce que l'on estime qu'il n'y a plus de leçons pratiques à tirer de la situation pour apporter des améliorations aux pipelines de Norman Wells ou à d'autres futurs projets semblables.

2. Il est recommandé que le gouvernement et l'industrie mettent en oeuvre des programmes coopératifs de recherche et d'observation portant sur d'autres projets nordiques en milieu pergélisolé, dans lesquels une évaluation pourrait conduire à des améliorations de l'atténuation des impacts ainsi qu'à

l'amélioration de la capacité d'anticiper les problèmes environnementaux.

3. Pour faciliter à la fois la planification et l'exploitation en toute sécurité des futurs pipelines ainsi que la maintenance suivie du pipeline de Norman Wells, une attention accrue devrait être apportée aux implications du changement climatique. L'accent devrait être mis sur l'analyse des tendances climatiques et de la variabilité du climat, de même que sur les conditions moyennes. Un changement climatique rapide peut limiter la validité des normales établies sur 30 ans en tant que paramètres de modèles géotechniques et géothermiques ainsi que de plans de protection de l'environnement.

4. Il est recommandé que les observations portent sur les points suivants : 1) la complexité et les mécanismes d'échange thermique entre la conduite et le sol (particulièrement dans des conditions de tranchées humides où le mouvement de l'eau, et partant, une transmission de chaleur par convection peut se produire) et 2) les effets des changements dans le régime thermique de la conduite sur le rendement thermique et, de ce fait, la stabilité des talus sensibles au dégel quand ils sont isolés.

5. Il est recommandé que l'emploi des copeaux de bois pour réduire le dégel du pergélisol dans les projets à venir tienne compte de méthodes pour : 1) garder sec les copeaux de bois pendant toute l'année et 2) restreindre la quantité d'air pénétrant dans la couche de copeaux de bois.

6. Il est recommandé que les points de franchissement des cours d'eau soient conçus en fonction des crues maximales en s'appuyant sur les connaissances géologiques et géomorphologiques, des modèles hydrologiques et des considérations basées sur des scénarios de changement climatique.

7. Il est recommandé que le droit de passage fasse l'objet d'une observation suivie et d'un entretien fréquent (hebdomadaire ou même plus souvent dans le cas du pipeline actuel et de futurs pipelines nordiques, spécialement pendant les premières années suivant leur construction), particulièrement après la période de ruissellement des eaux de fonte des neiges au printemps et les grandes tempêtes d'été. L'aménagement possible de bermes au mauvais endroit, l'omission des cours d'eau dans les calculs et une couverture végétale réduite rendent la surface du droit de passage particulièrement vulnérable à l'érosion pendant cette période.

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Abbreviations

(A number of abbreviations have been used for names and technical terms during the project review, research and monitoring, and subsequent reporting. For clarification we have listed abbreviations below.)

For Names

AG-CAN	Agriculture Canada
AES	Atmospheric Environment Service (Environment Canada)
CNT	Canadian National Telecommunications
CSA	Canada Standards Association
DIAND	Department of Indian Affairs and Northern Development (legal name) see INAC
EARP	Environmental Assessment and Review Process
EIS	Environmental Impact Statement
EMR	Energy, Mines and Resources
EPP	Environmental Protection Plan
ESSO	Esso Resources Canada Ltd.
FEARO	Federal Environmental Assessment and Review Office
GNWT	Government of the Northwest Territories
GSC	Geological Survey of Canada
INAC	Indian and Northern Affairs Canada (current reference to DIAND except in legal documents)
IPL	Interprovincial Pipe Line Limited or Interprovincial Pipe Line (NW) Limited
NEB	National Energy Board
NRC	National Research Council
N.W.T.	Northwest Territories (also NWT)
OC-35	Certificate of Public Convenience and Necessity No. OC-35 (NEB)
PCC	Project Co-ordinating Committee
PTRM	Permafrost and Terrain Research and Monitoring
ROW	Right-of-way (Also R.O.W.)

For Technical Terms

b/d	barrels/day
^{o}C	degrees Celsius (generally used unit for absolute temperatures)
gm/cc	grams per cubic centimeter
ha	hectare (1 ha = 100 m x 100 m)
K	degrees Kelvin (= ^{o}C, generally used unit for relative change in temperature)
km	kilometer
Kmp	kilometer post (also kp) location along pipeline
kPa	kilopascal (SI unit of measurement for pressure)
m	meter; m^3 = cubic meter; m^3/d = cubic meter per day
mm	millimeter
mPa	millipascal
mK/m	millikelvin per meter
W/mK	Watts per meter degree Kelvin
psi	pounds per square inch (unit of pressure, British system)
yd^3	cubic yards

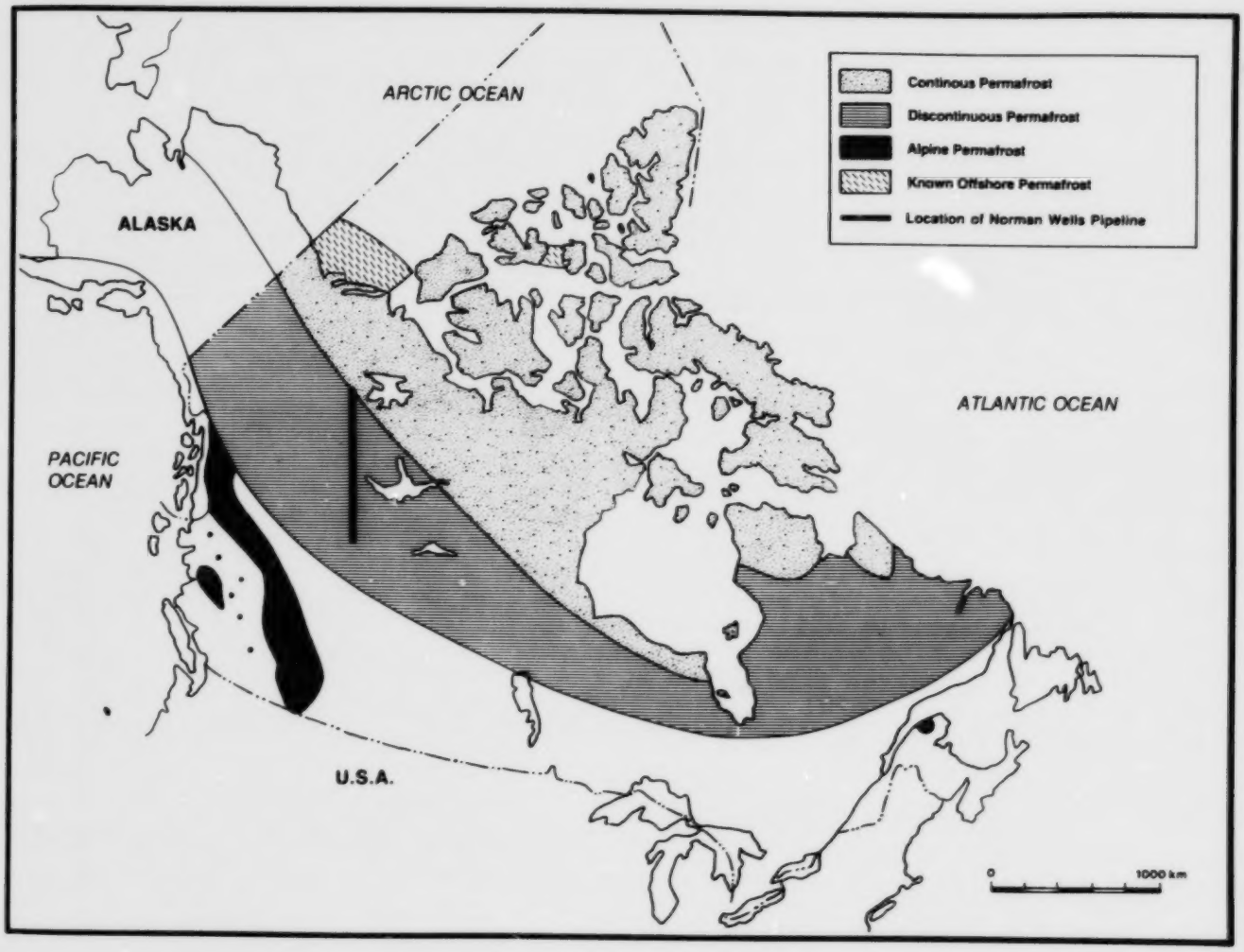


Figure 1-1. Location of the Norman Wells Pipeline in the discontinuous permafrost zone of northern Canada.

1. INTRODUCTION

The Norman Wells Pipeline provides a unique opportunity to examine the environmental impacts and the approaches used to minimize the impacts of the first completely buried oil pipeline in the discontinuous permafrost zone in northern Canada (Figure 1-1). In the discontinuous zone, a pipeline must traverse frozen and unfrozen ground at irregular but frequent intervals.

Safe pipeline operation and environmental protection in permafrost areas present many challenges: foremost of these relate to thermal conditions. Lessons learned from the Norman Wells Pipeline will assist in clarifying and evaluating environmental effects and in identifying improvements on the Norman Wells Pipeline and future projects. Under an Environmental Agreement, the Norman Wells Project is committed to the principle of "minimum practicable environmental and land use disturbance."

In permafrost terrain, major challenges for operation of a warm buried pipeline (operating temperature above 0°C) include possible slope instability and surface and pipeline settlement due to thawing of frozen ice-rich soil. Design of warm buried pipelines in permafrost requires prediction of the development of a "thaw bulb" around an operational pipeline (Figure 1-2a). In contrast, one of the major challenges for a chilled buried pipeline (operating temperatures below 0°C) is the potential for heave of frost-susceptible soil due to the upward movement of soil caused by the formation of ice within the soil. Design of chilled buried pipelines involves prediction of the development of a "frost bulb" around an operational pipeline. Surface disturbance from clearing, construction and use of right-of-ways also causes changes in the ground thermal regime and the potential for thawing of ice-rich soil.

One alternative to pipe burial is to elevate the pipeline in problem locations, as was done on the Trans-Alaska Pipeline System oil pipeline. Other alternatives include changing the characteristics of the pipe or its burial (e.g. refrigeration or insulation), or changing the pipeline operating temperature with location, such as operating a buried gas pipeline cold in continuous permafrost and warm in unfrozen ground (Workman, 1986). One of the complex decisions is whether to operate a warm or a cold pipeline in discontinuous permafrost.

A buried pipeline in discontinuous permafrost areas encounters transitions between frozen and unfrozen ground as well as transitions in soil (terrain) types. These transitions can present problems to both chilled and warm pipelines where differential heave or settlement of the pipe and the ground surface occurs

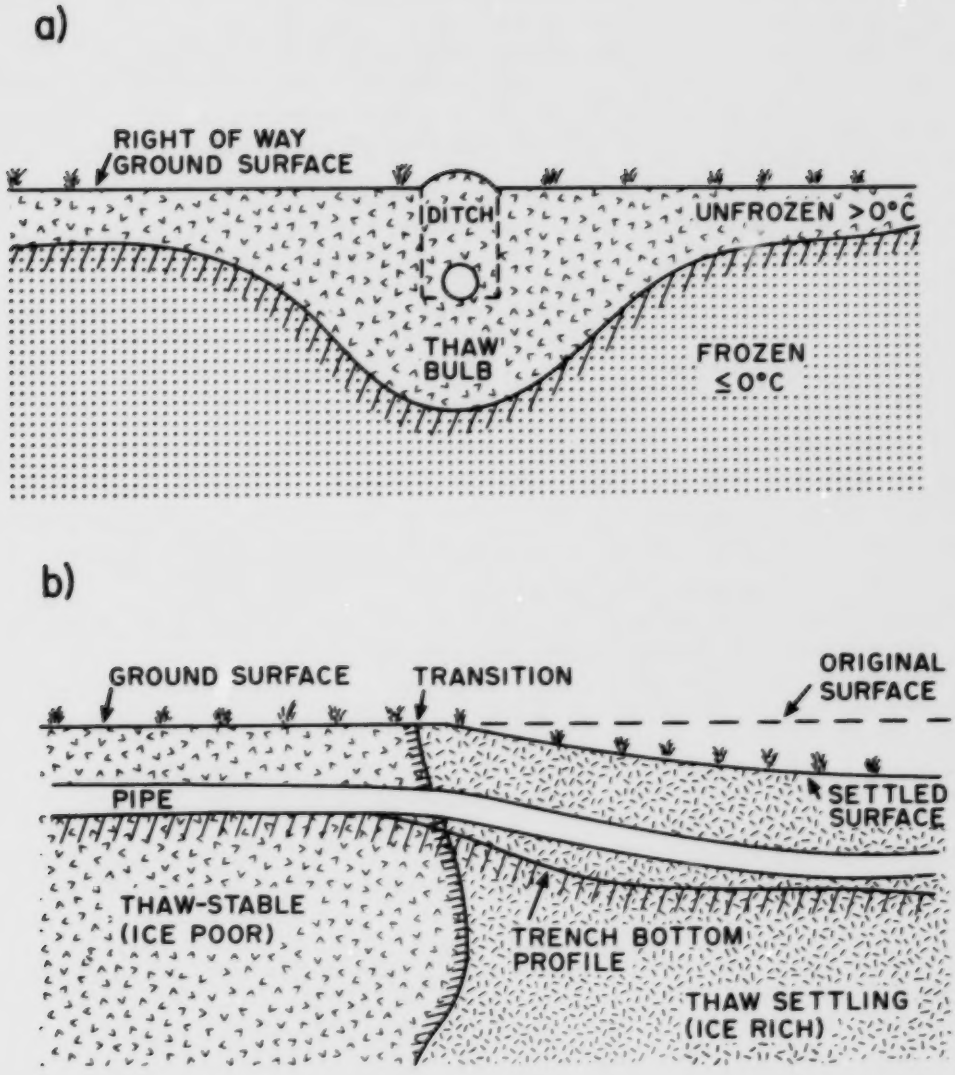


Figure 1-2. Diagrammatic sketch of a) a thaw bulb around a buried warm pipe and b) differential thaw settlement at a transition.

across the boundary, such as between a stable ice-poor granular soil and a thaw-sensitive ice-rich silty-clay soil (Figure 1-2b). These changes can also alter drainage and subsequent erosion.

Also of concern in permafrost areas is the additional impact of climate change or fluctuations. In discontinuous permafrost, where permafrost temperatures are near or just below 0°C, warming climate could result in an increase in the seasonally thawed layer at the surface (active layer), the degradation of permafrost, modification of surface and ground hydrological regimes, and in ice-rich terrain an increase in thaw settlement and slope instability. If continuous permafrost becomes discontinuous, transitions or interfaces become more of a concern. Conversely, a cooling climate could cause a thinning of the active layer, the development of permafrost, and additional frost heave in frost-susceptible soils. A changing climate could thus alter the predicted amounts of frost heave or thaw settlement or change stability estimates for thaw-sensitive slopes. Change to precipitation could also affect the ground thermal regime through modification of the snow cover, and affect drainage and erosion controls or water crossings through increased rainfall intensity and frequency of extreme storm events (Wigley, 1988; O'Donnell, 1989). (For definitions of some permafrost and pipeline related terms see glossaries in Appendix A.)

The Norman Wells pipeline is a completely buried pipeline using a small diameter (324 mm, 12.7 inch) pipe designed to operate at temperatures near the temperature of the surrounding ground ("ambient"), thereby minimizing both thawing and freezing around the pipe. In addition, Norman Wells pipeline designs provided for increased structural strength of the pipe (pipe grade and ductility, pipe wall thickness) under difficult soil conditions. This differs from the Trans-Alaska Pipeline System (TAPS) oil pipeline which is a large diameter (1.22 m, 48 inch), hot (operating temperature about 40 to 60°C) pipeline elevated above ground in thaw-sensitive terrain and buried in thaw-stable terrain.

The Norman Wells Pipeline Project underwent extensive environmental, technical, and socio-economic review. For background, the initial pipeline proposal and the regulatory agencies responsible for pipe safety and environmental protection are outlined in sections 1.1 and 1.2. A summary of events related to project reviews and implementation is given in section 1.3. Significant concerns related to the physical environment and engineering design and construction of the project identified by the Environmental Assessment Panel included (1) pipeline integrity and permafrost, (2) short and long term right-of-way stability (3) karst terrain, and (4) water crossings.

"Ambient" or warm temperature buried pipelines are under consideration for discontinuous permafrost segments of proposed gas

pipelines (Workman, 1986; Jahn and Heuer, 1982). Future pipelines are discussed briefly in section 1.4.

In 1982 an Environmental Agreement was signed between the Minister of Indian and Northern Affairs Canada (INAC) and the company proposing to build and operate the pipeline, Interprovincial Pipe Line (NW) Limited (IPL). Under this Environmental Agreement, the company and government agreed to develop and implement a monitoring program designed to "facilitate an evaluation of the impact management process in order to improve on impact evaluation and mitigation on the Norman Wells Pipeline and future projects". The Permafrost and Terrain Research and Monitoring Program is described in section 1.5 and in Volume II. The program focuses on the effects of construction, operation and maintenance of the pipeline on the surrounding soils under the prevailing climatic conditions through repeated observations of such factors as ground temperatures, moisture, and surface and slope stability. Analyses will also be used to improve prediction of potential climate change effects.

1.1 THE INITIAL PIPELINE PROPOSAL

Interprovincial Pipe Line (NW) Ltd., a wholly owned subsidiary of Interprovincial Pipe Line Limited based in Edmonton, Alberta, proposed to construct a pipeline to carry crude oil and natural gas liquids from Norman Wells, NWT, to Zama, Alberta, following a route along the east side of the Mackenzie River, crossing the river about 3 km east of Fort Simpson and proceeding in a southeasterly direction (east of Trout Lake) into northern Alberta (Figure 1-3). Initial plans, as presented in the Environmental Impact Statement (ESSO-IPL, 1980), included a small diameter pipeline (323.9 mm, 12.7 in) with three pump stations and a design capacity of about 5000 cubic meters of oil per day (32,000 barrels per day). The pipe would be buried throughout the full length of the route. To minimize ground thermal problems, oil would be chilled before it entered the pipeline in Norman Wells.

Approximately 760 kilometres (km) of the estimated 866 km (540 miles) length of the pipeline are within the Northwest Territories. It was estimated that pipeline construction would require a right-of-way (ROW) 30 m wide. Wherever possible IPL would use existing clearings or rights-of-way. About 1400 ha. of land were expected to be required for the pipeline and facilities (ESSO-IPL, 1980). Following construction, the ROW under lease would be decreased to 20 m in width.

The pipeline would be constructed primarily during the winter, using conventional wheel ditchers where feasible. Construction would utilize temporary winter access along the ROW as much as possible rather than construct all-weather road access. Facilities

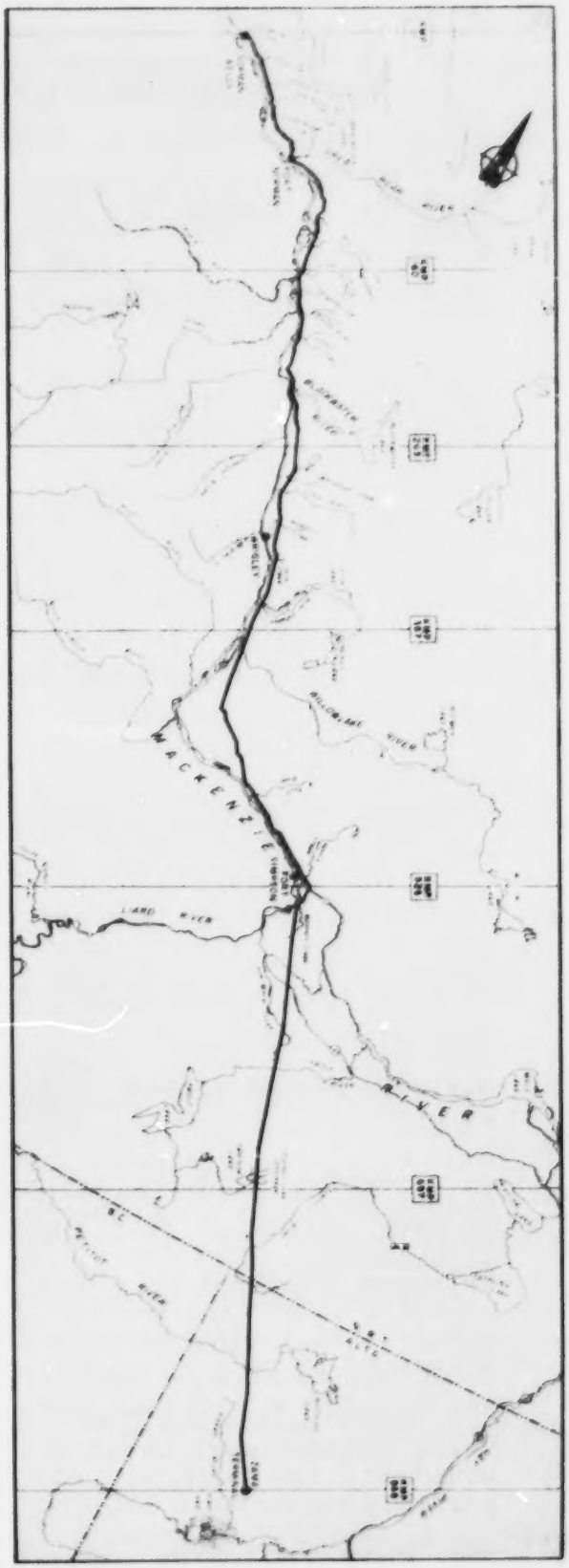


Figure 1-3.

Norman Wells to Zama pipeline alignment showing kilometre locations and some of the important water crossings.

such as pump stations and the major water crossings (Great Bear River and Mackenzie River) would be constructed in summer. The ditch was expected to be a minimum width of 1.1 m, and the pipe, as initially proposed, would be buried to a depth that would allow a minimum cover of 1 m over the pipe.

The ROW would be cleaned up, drainage and erosion control measures implemented, and the ROW and other areas seeded or reclaimed, primarily to promote soil stability. IPL indicated that they would monitor the pipeline (line patrols and special patrols) to identify and mitigate environmental and geotechnical problems. A control centre in Norman Wells would supervise operation of the pipeline.

At the conceptual stage of project planning, permafrost was "not expected to be a major problem" because of "the small size of the line and the fact that the oil will flow at ground temperature" (Environmental Impact Statement, ESSO-IPL, 1980). Temperatures of the flowing oil were expected to be determined by the ground temperature and to vary from -5°C in winter in permafrost areas to 7°C in summer in non-permafrost areas (ESSO-IPL, 1980). The lowest ground temperature expected at the pipe depth was -3.9°C (ESSO-IPL, 1980).

The expected terrain disturbances and main terrain related mitigative approaches (actions to reduce or ameliorate impact upon the environment) focused on thaw settlement, slope stability, drainage disruption, and the potential for subsequent erosion (IPL, 1982d). Specific designs and approaches are considered in more detail in Chapter 3. These designs and approaches primarily refer to those developed as a result of detailed project planning in 1980-1983.

1.2 REGULATORY AGENCIES

The proposed pipeline crossed only Crown lands. In the Northwest Territories the majority of the Crown lands are under federal administration by Indian and Northern Affairs Canada (Territorial Lands Act and Territorial Land Use Regulations). Short segments near Norman Wells and Fort Simpson are in Block Land Transfer areas and are administered by the Government of the Northwest Territories (GNWT). In Alberta the Crown lands are administered by the province's Department of Energy and Natural Resources. Most of the land areas crossed by or near the pipeline in N.W.T. are subject to Dene-Metis land claims. An Agreement In Principle was signed with the Dene-Metis in 1988; 1991 is the target date for completion of land selection.

Since the proposed pipeline crosses a territorial-provincial boundary, it also comes under the jurisdiction of the National

Energy Board (NEB), a quasi-judicial regulatory agency under the National Energy Board Act, which administers regulations governing the design, construction, operation, and abandonment of pipelines. NEB also regulates tolls and tariffs of pipeline companies under federal jurisdiction. In addition, licences, permits, and authorizations were required from various other federal, territorial, and provincial authorities.

1.3 PROJECT REVIEW AND RELATED CHRONOLOGY

The following is intended to give a brief background and chronology of some of the events (Table 1-1) related to the "impact management process", particularly to those related to permafrost and terrain. Completion of the Norman Wells Project from application to oil transportation took place over approximately five years, covering applications, reviews, agreements, regulatory approvals, development of monitoring programs, and constructing and testing the pipeline.

In 1979 IPL and Esso Resources Canada Limited (ESSO) initiated discussions with INAC and other government departments on the expansion of the Norman Wells Oilfield and the transportation of the oil by pipeline from Norman Wells to an existing pipeline in northern Alberta. On February 1, 1980, INAC referred the proposed project to the new Federal Environmental Assessment and Review Office (FEARO) for a full public review and assessment of environmental and socio-economic impacts.

In February and March 1980 Esso submitted an application to INAC for initiation of enhanced oil recovery and IPL filed applications for easements on Crown lands in the Northwest Territories (INAC, GNWT) and in Alberta, and for the necessary certificates and orders under the National Energy Board Act. Esso and IPL also submitted a joint four volume Environmental Impact Statement (EIS), "Norman Wells Oilfield Expansion and Pipeline Projects" (ESSO-IPL, 1980).

The Federal Environmental Assessment and Review Office established a review panel, conducted a series of public meetings, and in January 1981 submitted their report to the Minister of Environment (Duffy, 1981). The panel concluded that the project could be undertaken within acceptable limits of environmental and socioeconomic impacts providing important deficiencies were rectified in a) the Proponent's planning and b) the preparedness of government. One of the deficiencies cited was the lack of detailed thermal analysis of performance of the proposed pipeline for various terrain types and seasons of the year (Appendix B, item 5).

Table 1-1. Chronology for technical and environmental events.

Event	Date
IPL filed applications for easements and certificates, submitted Environmental Impact Statement (EIS)	March 1980
Report of the Environmental Assessment Panel completed	January 1981
NEB "Reasons for decision" completed	March 1981
Cabinet approves project	July 30, 1981
NEB issues Certificate of Public Convenience and Necessity	Oct. 29, 1981
Signing of IPL-INAC Agreements (3)	Sept. 28, 1982
IPL applied for Land Use Permit for "pre-clearing"	Nov. 1982
IPL applied for Land Use Permit for mainline construction	April 1983
NEB issued "Leave to construct"	June 1983
Mainline construction completed	Feb.- Mar. 1985
Official opening of pipeline	April 18, 1985
PCC (Project Co-ordination Committee) Wrap-up Review of Norman Wells project: Proceedings and Papers	Sept. 1985

The panel made twenty-seven recommendations on environmental and engineering concerns (Appendix C). Recommendations on "geotechnical concerns, pipeline integrity and permafrost" related to the following:

(1) timing of work and impacts (winter, summer)
(2) publication of a more detailed thermal analysis prior to project authorization which would in addition cover the possibility of climate change over the life of the pipeline
(3) preparation of detailed maintenance and repair plans prior to commissioning
(4) use of revegetation and erosion control programs shown to be adequate
(5) special oil spill contingency plans for karst terrain near Bear Rock and
(6) planning and construction of the pipeline to minimize the need for extensive subsequent maintenance and repair.

After holding public hearings in Edmonton, Yellowknife, and Ottawa, the National Energy Board (NEB) submitted its report on IPL's application entitled "National Energy Board Reasons for Decision" (NEB, 1981). The Board recognized the preliminary nature of the pipeline application and identified information which would be required from the applicant should a certificate be granted. This included information which the applicant proposed to collect or compile during 1981 and 1982 (e.g. geotechnical data, final locations and designs, environmental protection plans, training plans, and monitoring plans).

On July 30, 1981, Cabinet approved the construction of the Norman Wells Oil Field Expansion and Pipeline Project and directed the Minister of Indian and Northern Affairs to co-ordinate the Federal and Territorial governments' interests in the project. A pipeline co-ordination office was established in Yellowknife and a Project Co-ordinating Committee (PCC) was estabished which included government agencies, the proponents, and native organizations. The existing regulatory framework, rather than a special pipeline agency, was used for regulatory matters.

On October 29, 1981, the Governor in Council approved the issuance of the Certificate of Public Convenience and Necessity (No. OC-35). Within two months of certification, IPL was required to submit a schedule for filing studies and procedures (NEB, 1981). One of these reports was a reassessment of plans to minimize terrain damage along the pipeline (IPL, 1982d).

In August 1982 the Government of Northwest Territories asked the Department of Environment's Environmental Protection Service in Yellowknife to co-ordinate a federal and territorial initiative to develop a research and monitoring program for the Norman Wells Project. This resulted in the formation of the "Norman Wells

Research and Monitoring Working Group" which met and reported annually (1983-1987), in the Northwest Territories. The Permafrost and Terrain Program was developed as part of the overall Working Group program. Most of the other Working Group projects emphasized impacts during the construction period, and were terminated one to two years after construction (Environmental Protection Service, 1984; Boreal Ecology, 1985, 1986, 1987 and 1989a).

In September 1982 the Minister of Indian and Northern Affairs entered into three agreements with Interprovincial Pipe Line (NW) Ltd.:

(1) A Socio-Economic Agreement
(2) a Right-of-Way Agreement, granting the pipeline easement, and
(3) an Environmental Agreement, establishing principles of environmental protection, co-operative monitoring, and an evaluation of environmental management.

The Environmental Agreement responded to concerns raised during the various review processes and emphasized the basic principle of "minimum practicable environmental and land use disturbance" (Appendix D). The company specifically agreed to implement mitigation measures for environmental as well as engineering purposes in permafrost areas (Clause 7).

IPL applied for a Land Use Permit for clearing part of the right-of-way (ROW) in November 1982 and "pre-construction" clearing commenced in January 1983 on the specified areas (approximately 1-2 years behind the Company's original proposed schedule). On April 7, 1983 IPL applied for a land use permit (including stream crossing Water Authorizations) for the completion of the clearing of the ROW and for subsequent mainline construction of the pipeline. The Land Use Permit for mainline construction was issued on May 18, 1983, except for approval of wood chips for insulation of thaw-sensitive slopes.

By June 1983, the remaining environmental, engineering, and socio-economic studies had been completed to the satisfaction of NEB and NEB issued a "Leave to Construct" order to IPL. Following additional review of the use of wood chips as insulation on slopes, INAC authorized IPL to proceed (land use permit) with their use.

Regulatory and co-ordination activities were reviewed by government, industry and native groups and a summary report was prepared by the Pipeline Co-ordination Committee (1985). The INAC Pipeline Co-ordination Office was closed and the INAC Chief Surveillance Officer's duties were turned over to the respective INAC Offices in Norman Wells and Fort Simpson. Although the post-construction ROW and other facilities are leased to IPL, access and other related activities continue to require permits such as land use permits and quarry permits. INAC and IPL meet at least annually to review activities in respect to the Environmental

Agreement which continues until the pipeline easement is terminated or surrendered.

1.4 FUTURE PIPELINES

Various designs are being considered for Mackenzie Delta - Beaufort oil and gas pipelines of small (12 in.) to medium (24 in.) to large (34-48 in.) sizes. Preliminary discussions and proposals include a range of possible construction modes from fully buried, to elevated only in thaw-sensitive slopes, to about one-third elevated. Gas pipeline scenarios include different thermal designs in continuous, discontinuous and non-permafrost areas (Workman 1986). Economic pressures may lead toward less conservative pipeline design, operation and maintenance approaches, e.g. thinner pipe walls, conventional non-permafrost construction practices and less frequent monitoring. Unlike small pipelines where it is anticipated that ground conditions will dominate the ROW, large pipelines are expected to dominate adjacent ROW thermal conditions.

Some of the critical permafrost and terrain issues for cost-effective environmentally-safe overland construction and operation of either Beaufort oil or gas pipelines include:

(1) thaw-sensitive slopes
(2) stability of ice-rich terrain
(3) differential frost heave or thaw settlement
(4) influence of climate change on design, operation and environmental protection
(5) extent of effects and resources, eg. borrow materials associated with larger diameter pipelines.

These issues will continue to be of high concern in the discontinuous permafrost zones, where warming climate trends could result in considerable change during the operational life of a pipeline especially on thaw-sensitive slopes. Potentially increased intensity and frequency of extreme summer rainstorms are of concern.

1.5 PERMAFROST AND TERRAIN RESEARCH AND MONITORING PROGRAM

The Departments of Indian and Northern Affairs (INAC) and Energy, Mines, and Resources (EMR) initiated preliminary plans in 1983 for a co-operative permafrost and terrain research and monitoring program with Interprovincial Pipe Line (NW) Ltd. under the "Environmental Agreement" signed between IPL and INAC in 1982. The research and monitoring goal, as established in the Environmental Agreement, is to improve impact evaluation and mitigation on the Norman Wells pipeline and future projects.

The program initiated in 1983 consisted of two projects: (1) to monitor permafrost, terrain and terrain stability along the right-of-way by instrumenting selected sites (Permafrost Research Section, GSC, EMR) and (2) to evaluate terrain performance along the right-of-way by periodic observation (Geomorphic Processes and Engineering Geology Section, GSC, EMR). Two additional projects were initiated in 1986 to augment (a) the evaluation of wood chip insulation (Institute for Research in Construction, National Research Council) and (b) the evaluation of surface soil (0.025 m to 1.5 m) and air temperatures at selected sites (Land Resources Research Centre, Agriculture Canada). Results from the latter project will be presented in subsequent reports.

The Permafrost and Terrain Research and Monitoring (PTRM) Program objectives are (1) to determine and quantify impacts on permafrost and terrain, (2) to evaluate recovery processes and effectiveness of mitigative measures, (3) to compare actual and predicted impacts, (4) to assess the adequacy of the regional environmental framework and (5) to recommend improved environmental practices. The objectives were also established to address goals of the Norman Wells Research and Monitoring Working Group. Monitoring is planned for 5 to 10 years or until conditions stabilize.

The PTRM observations also contribute to the performance evaluation required annually under the Environmental Agreement between INAC and IPL. The Environmental Agreement continues until the pipeline easement is terminated or surrendered, or until the pipeline is abandoned or removed.

The "research and monitoring program" is distinct from (1) the pipeline operator's monitoring (e.g. standard operational line patrols; geotechnical and other environmental or pipe condition monitoring) and (2) the legal regulatory surveillance and monitoring pursuant to Acts and Regulations. It works in close cooperation with both the Company and relevant regulators and shares the same broad goal of identifying impacts and improving mitigation. Any potential problems identified during monitoring field trips (e.g. exposed pipe, tension cracks, streambank erosion) are identified immediately to both IPL and INAC regulatory staff, in some cases directly via helicopter radio or telephone contact. Thermal data is provided to the Company immediately after each field trip and released to the public annually in GSC Open File reports (with the exception of wood chip thermal data which is considered proprietary until January 1990).

Monitoring from 1984 through 1987 was approximately monthly for most of the N.W.T. portion of the ROW with emphasis on the thaw season. The frequency of monitoring was reduced to 6-8 week intervals in 1988, retaining the emphasis on the thaw season. A list of reports based on the PTRM is in Appendix E. Results of the program are discussed in Volume II of this report.

2. REGIONAL ENVIRONMENTAL FRAMEWORK

This chapter provides background information on the environmental setting along the Norman Wells pipeline corridor, in particular the climate, terrain, permafrost, vegetation and soil conditions. These reviews provide a framework for the discussions to follow on pipeline design, construction, operation and mitigation of impacts, as well as for the discussions in Volume II on the monitoring program observations and results. The material is presented with an emphasis on the data available or used in the final detailed pipeline design. Additional information may also be included. Data collected or compiled as part of the permafrost and terrain research and monitoring program is presented along with the analyses and results in Volume II of this report.

2.1 CLIMATE

Analysis of the climatic regime within the pipeline corridor is based primarily upon the record of Atmospheric Environment Service, Environment Canada, (AES) meteorological stations at Norman Wells, Fort Norman, Wrigley and Fort Simpson (Table 2-1). Although the major focus in this section is on the review of 30-year climate normals, it is important to also consider climatic trends and the implications of contemporary and future climatic change. Major limitations to the existing climatic data base result from:

(a) the short period of the record and incompleteness of the data set (for example, data are not currently collected at Fort Norman and Wrigley on weekends and frequent other gaps occur in the record). This limits the usefulness of the record in predicting either mean or extreme conditions over the lifetime of the pipeline project. Essentially, such predictions are based on analysis of the full record which exists at only two stations, Norman Wells and Fort Simpson.

(b) the irregular but generally wide spacing of the stations (ranging from 65 km between Norman Wells and Fort Norman to over 400 km between Fort Simpson and High Level, the nearest AES station to the southern terminus of the pipeline). This precludes interpolation of meteorological conditions at intermediate locations and implies that major storm events could cross the pipeline route undetected.

(c) the location of all Mackenzie Valley stations at sites adjacent to the river. This results in a data set which is unrepresentative of the complex terrain along the pipeline

Table 2-1. Location of Environment Canada (AES) and GNWT[1] fire weather sources of meteorological data near the Norman Wells Pipeline right-of-way.

STATION NAME	CODE NAME	Latitude	Longitude	Elevation (m)
Norman Wells A	VQ	65°16'N	126°47'W	98
Fort Norman A/GNWT	FN	64°54'N	125°35'W	73
Eagle Ridge Tower	EAGL	64°03'N	124°06'W	610
Mount Gaudet Tower	GDET	63°22'N	123°38'W	587
Fort Simpson HQ	FSHQ	61°53'N	121°23'W	123
Fort Simpson A	FS	61°52'N	121°22'W	123
Redknife Hills Tower	REDK	60°37'N	119°56'W	796
Trout Lake Tower	TROU	60°33'N	121°35'W	747

Notes:

1. Source: Government of the Northwest Territories (GNWT)
   Territorial Forest Fire Centre
   Department of Renewable Resources
   P.O. Box 7
   Fort Smith, N.W.T. X0E 0P0

   "A" refers to AES location at airports, "HQ" refers to location at G.N.W.T. Renewable Resources Office.

2. Most fire weather records were started in 1982 or later and are summer only (mid-May to mid-August). Seasonal weather records will be entered into a computerized data base in 1988-89. Records from Eagle Ridge Tower are incomplete.

3. Additional automatic AES climate stations have been installed at Canyon Creek (1985) and Kee Scarp, Norman Wells (1988) in cooperation witn EMR and INAC.

route. In particular, environments within tributary valleys and at higher elevations are likely to experience significant variation in both daily and seasonal climate (Dome, Esso and Gulf, 1982).

Additional meteorological data are available on a seasonal (mid-May to mid-August) basis from stations operated by the Territorial Forest Fire Centre, Government of the Northwest Territories (see Table 2-1). Because some of these are situated at locations between the AES stations, and at higher elevations away from the Mackenzie River, they make an important contribution to reducing the data gaps described above.

From 1985 to 1988 EMR and INAC cooperated with AES in the installation of automated climate stations at three sites established for long term study of climate change and ground temperature relationships in the Mackenzie Valley. These remote stations were located as follows: i) in 1985, at Canyon Creek approximately 20 km south from Norman Wells along the pipeline right-of-way, ii) in 1988, at Kee Scarp, about 5 km north of, but within, the municipality of Norman Wells, and iii) in 1988, at Gibson Gap, approximately 100 km northwest of Norman Wells. The records from these new stations will also make an important contribution in reducing data gaps in the Valley.

AES and GNWT meteorological data are also available at several sites north of Norman Wells, within the proposed development corridor (Table 2-2). These data will be of considerable importance in establishing baseline environmental conditions and design criteria for future Mackenzie Delta - Beaufort pipeline projects.

Table 2-2. Location of Environment Canada (AES) and GNWT [1] fire weather sources of meteorological data north of Norman Wells, within the proposed development corridor.

STATION NAME	CODE NAME	Latitude	Longitude	Elevation (m)
Inuvik A	EV	68°18'N	133°28'W	68
Sunny Lake	SUNY	67°51'N	132°35'W	250
Arctic Red River	ARRR	67°26'N	133°44'W	30
Grandview	GRVW	66°43'N	130°50'W	49
Fort Good Hope A	GH	66°15'N	128°36'W	67

Notes:

1. Source: Territorial Forest Fire Centre (GNWT)
2. An additional AES automatic climate station has been installed at Gibson Gap (1988), 65°46'N and 127°55'W, in cooperation with EMR and INAC.

In general, the Norman Wells Pipeline corridor experiences a cold, continental climate with a wide annual temperature range and relatively low levels of precipitation (Burns, 1973; 1974). These conditions are illustrated by the 1951-1980 climatic normals for Environment Canada meteorological stations located on or near the pipeline route (Table 2-3). The long winters are cold, with mean monthly temperatures below -20°C , while the summers have three months with mean temperatures above 10°C. Except in the extreme south of the corridor, mean monthly air temperatures are below 0°C for seven months, from October to April.

TABLE 2-3 : CLIMATIC NORMALS (1951-1980) FOR SELECTED AES STATIONS ALONG THE PIPELINE CORRIDOR

Mean Daily Air Temperature (C)

STATION	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	S.D.
Norman Wells A	-28.9	-26.2	-19.8	-7.2	5.4	14.0	16.3	13.4	6.1	-4.6	-18.2	-26.5	-6.4	1.0
Fort Norman	-28.6	-25.9	-19.4	-7.0	5.3	13.3	16.0	13.3	6.3	-4.4	-18.2	-26.0	-6.3	1.0
Wrigley A	-29.4	-24.6	-16.6	-3.6	7.3	14.0	16.3	13.8	6.6	-3.5	-17.0	-26.0	-5.2	0.9
Fort Simpson A	-28.2	-22.8	-14.9	-2.5	7.9	14.4	16.6	14.4	7.3	-1.9	-15.6	-24.5	-4.2	1.0
High Level A	-24.6	-18.5	-11.8	0.8	9.3	13.6	15.7	14.0	8.1	1.3	-11.4	-20.3	-2.0	1.1

Mean Monthly Precipitation (mm)

STATION	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	S.D.
Norman Wells A	19.5	16.1	12.9	15.4	17.0	37.0	56.1	58.6	29.3	26.8	20.9	18.8	328.4	74.0
Fort Norman	13.9	11.7	15.3	14.4	23.6	47.5	46.1	50.6	30.5	35.1	22.0	14.2	324.9	118.3
Wrigley A	18.5	12.2	13.5	17.5	27.2	43.5	54.3	46.0	30.2	32.7	19.4	20.2	335.2	93.0
Fort Simpson A	19.9	19.0	21.7	14.6	31.1	38.7	59.3	44.8	31.3	24.0	27.2	23.5	355.1	77.1
High Level A	20.6	15.9	16.2	17.4	35.5	53.2	68.9	57.8	33.9	14.7	27.9	24.7	386.7	73.5

Mean Monthly Snowfall (cm)

STATION	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Norman Wells A	20.6	17.3	13.6	15.3	8.4	0.6	0.1	T	5.3	25.0	21.3	19.3	146.8
Fort Norman	14.7	12.6	16.2	12.1	11.0	1.8	-	-	5.9	32.7	22.7	14.6	144.3
Wrigley A	19.2	12.5	13.5	14.9	6.6	T	-	-	3.0	27.9	19.7	20.0	137.3
Fort Simpson A	20.7	18.9	21.2	11.7	5.1	-	-	-	5.7	18.5	25.3	23.9	151.0
High Level A	26.6	20.6	21.0	14.5	4.3	-	-	-	1.3	15.3	29.1	30.9	163.6

Source: Canadian Climate Normals (1951-1980), Atmospheric Environment Service, Environment Canada.

There is a general north-south increase in temperature along the pipeline route; mean annual temperature is -6.4°C at Norman Wells, -4.2°C at Fort Simpson, and -2.0° C at High Level. South of Fort Simpson, the pipeline rises to elevations over 200 m a.s.l. on the Alberta Plateau, resulting in a reversal of the latitudinal temperature trend. Local temperature differences are also superimposed upon the general north-south temperature trend. For example, river valleys and other regions of low terrain are generally areas of local winter temperature minima due to cold air drainage and effects of the characteristic Arctic inversion. By contrast, these same areas may be sites of local summer temperature maxima relative to areas of surrounding higher ground. For these reasons, the thermal regime of the pipeline corridor tends to be characterized by large meso-scale variability (Dome, Esso and Gulf, 1982).

Precipitation levels within the pipeline corridor are directly related to topography; for example Burns (1974) estimated that there is a 20% increase in precipitation per 1000 ft (330 m) increase in elevation within the Mackenzie Valley south of Fort Good Hope. All meteorological stations used for climatic analysis within the pipeline corridor lie at elevations below 200 m; thus, precipitation levels recorded are likely to represent minima for the pipeline route as a whole, and in particular for sections of the route crossing the Alberta Plateau. At Norman Wells and Fort Simpson, mean annual precipitation is in the range 330-380 mm, of which 30-40% occurs in the form of snow (based on data collected in 1951-1980).

The records at AES stations indicate considerable year to year variation in both total precipitation and snowfall. In any month of the year, total rainfall or snowfall may vary from zero to almost double the mean (Burns, 1974). Precipitation is most frequent during the winter, in the form of light snowfalls, but 45-55% of the annual total occurs as rainfall during the period June-September.

Two aspects of the precipitation regime are of particular importance to the pipeline project. First, from the perspective of predicting and controlling right-of-way erosion, summer rainfall intensity is a critical factor determining both overland flow and channel discharge. Rainfall within the pipeline corridor occurs between April and November; however, peak rainfall occurs during the period June to September, often in the form of intense rainstorms. In most cases, the area affected by such storms is smaller than the spacing between meteorological stations. For this reason, it is not always possible to identify either the chronology or intensity of storm events which result in right-of-way erosion. A further complication is that storm events within Mackenzie Mountain catchments may produce discharge peaks at pipeline water crossings located outside the area directly affected by the storm.

Second, snow depth and duration of snowcover may both constrain and facilitate winter construction and remedial activities. For example, an early deep snow cover slows the rate of frost penetration and therefore limits overland vehicle usage. On the other hand, a minimum snow cover is required to protect the ground surface from excessive disturbance, and determines the overall window for winter construction activities. Snowcover depth and duration are important factors controlling ground thermal regime and have also influenced the thermal performance of wood chip insulation on slopes (see Volume II).

Maximum 24-hour precipitation values have been calculated for given return periods at meteorological stations in the Mackenzie Valley (Table 2-4; Burns, 1974). A return period of 50 years was adopted for the design calculations relating to surface erosion on overland sections of the pipeline route (IPL, 1983a). Predicted 24-hour maximum precipitation for a 50-year return period is 63.5 mm at Norman Wells and 71.1 mm at Fort Simpson. It is likely that these values would be greater at higher elevations on the pipeline route.

Table 2-4. Return period of maximum 24-hour precipitation (mm) at AES meteorological stations close to the Norman Wells Pipeline right-of-way.

	RETURN PERIOD (YEARS)							
STATION NAME	1.1	2	6	10	20	30	40	50
Norman Wells A	15.2	25.4	35.6	43.2	53.3	58.4	63.5	63.5
Wrigley A	17.8	25.4	33.0	38.1	43.2	N/A	N/A	N/A
Fort Simpson A	15.2	27.9	43.2	50.8	61.0	66.0	68.6	71.1

Source: Burns (1974). N/A: not available

Based upon analysis of the 1951-1980 record, mean annual snowfall does not vary much between the four AES meteorological stations located along the pipeline route, ranging from 120-140 cm per year (Burns, 1974). However, large variations occur both from year to year and between stations within the same year. In general, snowfall begins in late-September and the highest snowfall

occurs between October and December. A snowcover of at least 2.5 cm depth is present in the Mackenzie Valley, on average, from late-October to early-May (i.e about 200 days), although at the southern end of the pipeline corridor continuous snowcover may be limited to the period December-March. Mean maximum snow depth ranges between 40 cm and 100 cm, and usually develops by January-February. Estimated average snow density increases throughout the winter season from 0.174-0.265 gm/cc at Fort Simpson, and from 0.236-0.284 gm/cc at Norman Wells (Burns, 1974).

The climatic data base summarized above was used by IPL to derive two schemes of climatic zonation. The first, used as a regional framework for geothermal analyses relating to frost heave/thaw settlement potential, was based on earlier analyses by Canadian Arctic Gas Study Limited (IPL, 1980). These zones are described in detail in section 2.3.2. The second scheme was used as a framework for predictive models of drainage conditions and erosion control requirements, based upon the development of intensity-duration-frequency (IDF) plots of precipitation (see e.g. Gray, 1970). Three zones were defined as follows (IPL, 1980):

Zone 1: Zama - Fort Simpson (km 527-868)
Zone 2: Fort Simpson - Fort Norman (km 78-527)
Zone 3: Fort Norman - Norman Wells (km 0-78)

2.2 TERRAIN

Studies of the geology and geomorphology of the Mackenzie Valley transportation corridor, between the Beaufort Sea and the Territorial/Provincial boundary, were undertaken during the 1970's and 1980's in relation to earlier pipeline proposals. A major program of the Geological Survey of Canada provided maps of surficial geology, terrain classification and terrain sensitivity for the entire corridor at a scale of 1:250,000. Many of the results of these investigations were published as reports of the Environmental-Social Program Northern Pipelines, Task Force on Northern Oil Development. For example, terrain conditions along the pipeline route north of 64° (i.e. north of Blackwater River, km 220) have been described by Hughes et al., (1973), while terrain conditions south of 64° (i.e. south of Blackwater River) have been documented by Rutter et al., (1973). Geotechnical studies have been undertaken by Code (1973), Isaacs (1974), McRoberts and Morgenstern (1973) and Savigny (1989). Terrain disturbance susceptibility in the vicinity of Norman Wells has been investigated by Kurfurst (1973).

The Mackenzie Valley Geotechnical Data Bank (Proudfoot and Lawrence, 1976) contains over 11,000 records of borehole logs located between Richards Island and the southern Mackenzie Valley.

It should be noted, however, that the data bank was of only limited use in planning the geotechnical design of the Norman Wells Pipeline as, (a) the records are of variable quality, (b) the earlier drilling programs were not oriented towards the specific design criteria of this pipeline and, (c) few boreholes were located on or near the IPL right-of-way. To provide the required information, pre-construction geophysical and geotechnical programs were carried out along the pipeline route (IPL, 1980; 1982e).

The Norman Wells pipeline traverses three major physiographic regions, the Mackenzie Plain, Great Slave Plain, and the Alberta Plateau (Figure 2-1). Between Norman Wells and Fort Simpson, the pipeline follows the east bank of the Mackenzie River (Figure 1-3), crossing a number of major tributaries including Great Bear River near Fort Norman (km 78) and Willowlake River south of Wrigley (km 380). The Mackenzie River is crossed just east of Fort Simpson (km 578), after which the pipeline strikes southward across the Alberta Plateau to Zama. The topography along most of the pipeline route is relatively subdued, as no mountain barriers are crossed. In the north, the steepest slopes are encountered at crossing points of valleys deeply incised by streams flowing into the Mackenzie River (Figure 2-2). The highest elevation on the line, 680 m.a.s.l., is attained as it crosses the Redknife Hills, approximately midway between Fort Simpson and the Zama pipeline terminus.

The entire pipeline route was covered by ice during the last glaciation, and most areas are underlain by unconsolidated glacial and postglacial deposits. Thick till sequences were encountered in the EMR/INAC 93 m deep borehole at km 271. Following deglaciation, much of the Mackenzie Valley was occupied by a series of large glacial lakes. These were associated with the deposition of extensive areas of lacustrine silt and the formation of wave-washed boulder beaches. Bedrock is rarely exposed at the surface, and is encountered along only 2% of the pipeline route (Kay et al., 1983). It occurs at shallow depths between Pump Station 1 and Canyon Creek (km 0-19), near Bear Rock (km 78), at Big Smith Creek (km 142) and Willowlake River (km 380), and at several localities south of the Mackenzie Highway crossing. In areas adjacent to the Franklin Mountains, surficial materials are underlain by carbonate bedrock. This gives rise to a variety of karst landforms, characterized by subterranean water flow and bedrock solution (Figure 2-3).

Route characterization was undertaken by IPL prior to construction, resulting in the development of data bases and statistics to describe variation in environmental conditions along the pipeline route. The data were presented graphically in the form of 1:20,000 scale terrain-typed air photo mosaics (IPL, 1982b), and used as an input into models of frost heave/thaw settlement and drainage/erosion control. Four main elements were used in terrain typing the Norman Wells pipeline route. The first

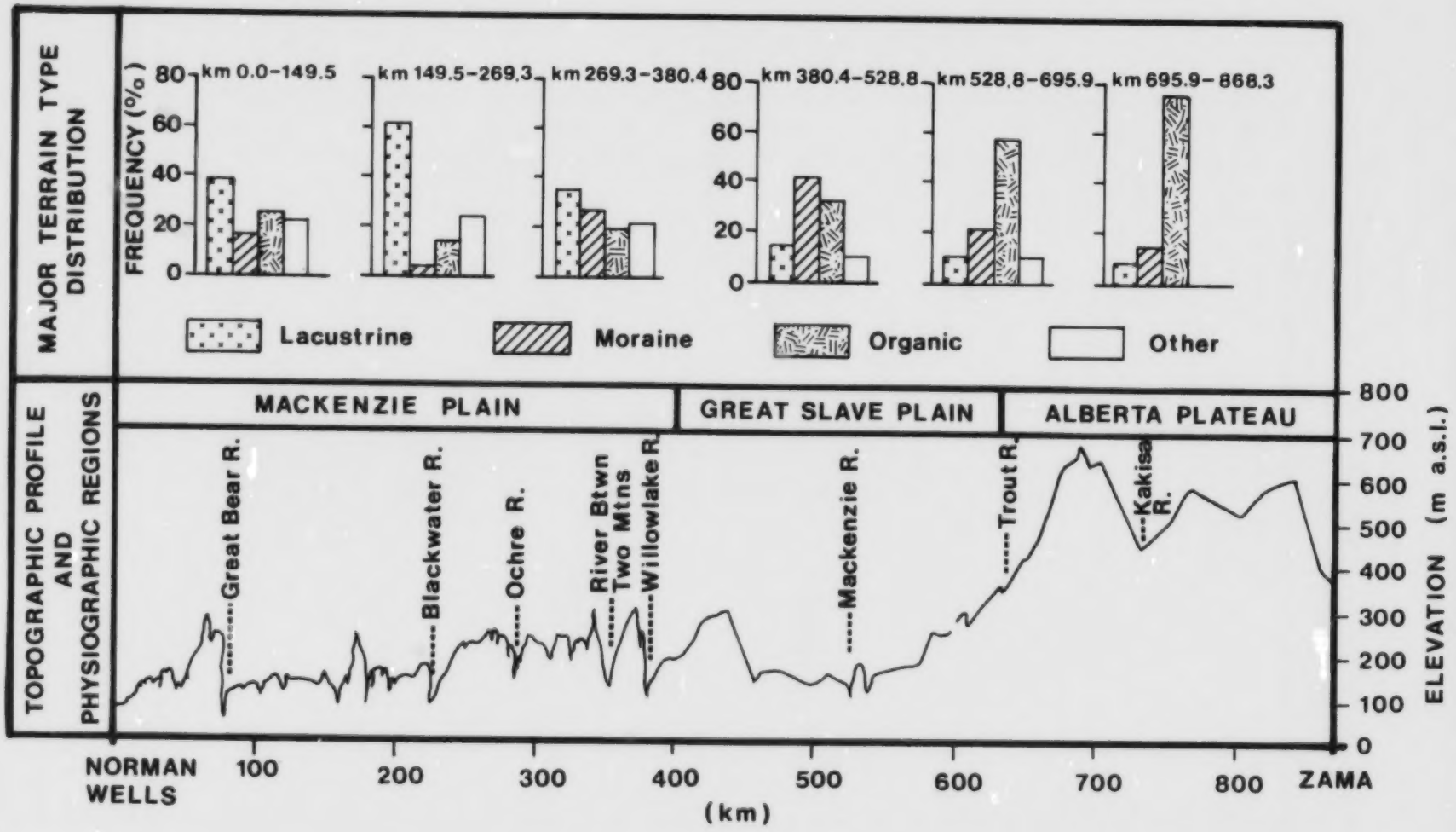


Figure 2-1. Topographic profile along the Norman Wells pipeline right-of-way, showing relationship to physiographic regions and generalised terrain type distribution.

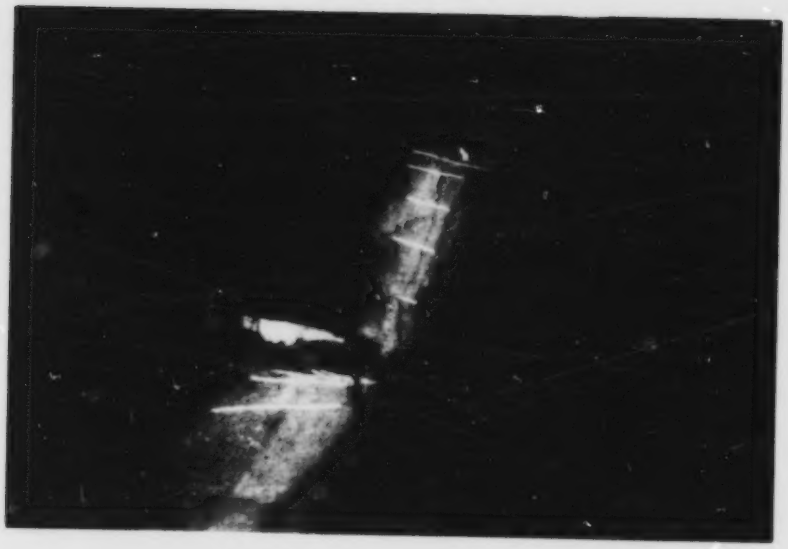


Figure 2-2. Pipeline crossing of Unnamed Creek, km 196, view south. (06/06/85)

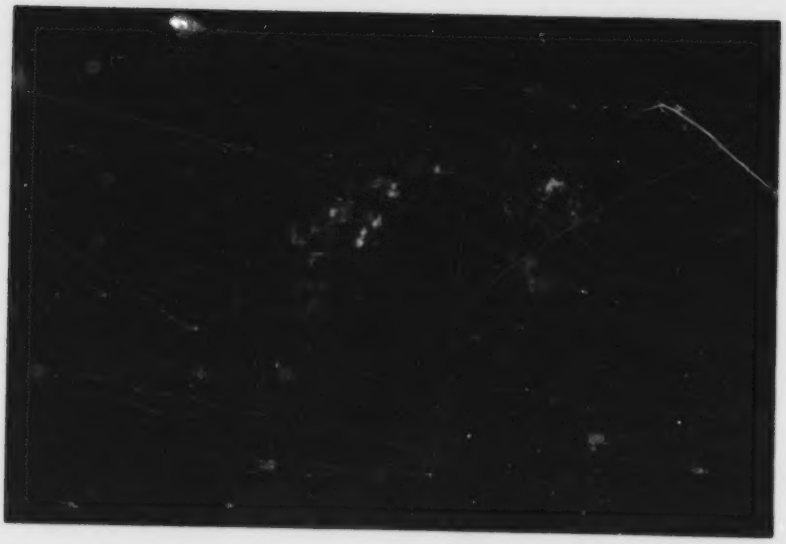


Figure 2-3. Sinkhole developed in karst terrain, about 3 km northeast of pipeline, near Vermillion Creek, km 43. (05/08/83)

two define morphogenetic landscape units, by establishing landform genetic class (i.e. the geologic process or set of related processes responsible for deposition of the surface material) and specific landform type. The third element defines sediment texture and the fourth, where appropriate, provides a process modifier. A listing of terrain type categories mapped on the Norman Wells pipeline is provided in Table 2-5. An example of the use of these units on terrain-typed alignment sheets is shown in Figure 2-4.

The distribution of terrain types within each construction spread has been analyzed by Kay et al. (1983), and is summarized in Table 2-6. To simplify this analysis, some of the less commonly occurring terrain types have been grouped (see IPL, 1982f). Between Norman Wells (km 0) and Willowlake River (km 380), lacustrine and moraine (till) terrain types predominate, accounting for 50-60% of the total. From Willowlake River south to the Mackenzie River crossing (km 528) the moraine component becomes dominant, accounting for more than 40% of the total. South of the Mackenzie River crossing, there is a marked increase in the proportion of organic terrain, which characterizes nearly 50% of the southern segment of the pipeline route (Figure 2-5).

Stream crossings represent particularly dynamic geomorphic locations on the pipeline route. This is especially true of the northern part of the alignment, where tributary streams to the Mackenzie River rise in mountainous areas and possess irregular and widely fluctuating discharge regimes. They are frequently characterized by braided channels, between which the main river flow may periodically shift. In addition, many streams are fed by perennial springs and thus develop extensive winter icings and ice jams during spring breakup. Both factors contribute to periodic high water events. The hydrological data base, from which estimates of flood frequency may be derived, is limited. The Water Survey of Canada maintains gauging stations on only 7 of the 51 streams and rivers crossed by the pipeline in the N.W.T. which had site specific designs (see section 3.8). Furthermore, only at Great Bear River, Mackenzie River, and Kakisa River was the period of record sufficiently long to permit direct estimation of the 100 year return peak flood discharge used in the crossing designs (IPL, 1982c).

Table 2-5. Terrain type classification employed on the Norman Wells Pipeline project.

GENETIC ORIGIN AND LANDFORM TYPE

O - Organic landforms:
- b - patterned bog lands, peat plateaus and palsas
- f - ribbed (string), reticulated and horizontal fen lands
- u - undifferentiated and transitional bog-fen complexes
- v - organic veneer

A - Alluvial landforms:
- c - channel, wholly or partly water covered
- d - delta
- f - fan
- p - flood plain (may or may not be inundated)
- t - terrace (not flooded)
- v - alluvial veneer

C - Colluvial landforms:
- a - apron
- f - flow slide (mudflow and debris flow)
- m - slopewash and rill sheet wash
- s - slide
- t - talus slope
- v - slopewash veneer

E - Eolian landforms:
- b - sand and loess blanket
- d - dunes
- v - eolian veneer

L - Lacustrine and Glaciolacustrine landforms:
- b - postglacial basin
- d - deltaic plain
- p - nearshore and offshore lake plain
- r - raised beach ridge
- v - glaciolacustrine veneer

G - Glaciofluvial landforms:
- d - delta
- e - esker, esker complex
- k - kame, kame complex, kame terrace
- p - outwash plain
- t - terrace
- v - glaciofluvial veneer

M - Moraine landforms:
- a - ablation moraine
- c - crevasse filling
- d - drumlin, drumlinoid moraine
- e - end moraine
- g - ground moraine
- h - hummocky moraine
- r - ridged
- v - moraine veneer

R - Bedrock (undifferentiated)

OVERBURDEN TEXTURE
- b - boulders and/or angular blocks
- c - clay, clay and silt and/or sand
- g - gravel, including sandy and cobbly mixtures
- m - silt, including minor clay and/or sand mixtures
- o - organic component
- p - peat
- s - sand
- t - till

MODIFIERS
- A - avalanched
- C - channeled
- E - eroded
- G - gullied
- K - karst
- P - pitted or kettled
- S - soliflucted
- T - thermokarsted

Example: Single overburden landforms: gtMg-G = Moraine (genetic type M), ground moraine (landform type g), till (main material type t), gravel (subordinate material type g), gullied (modifier G)

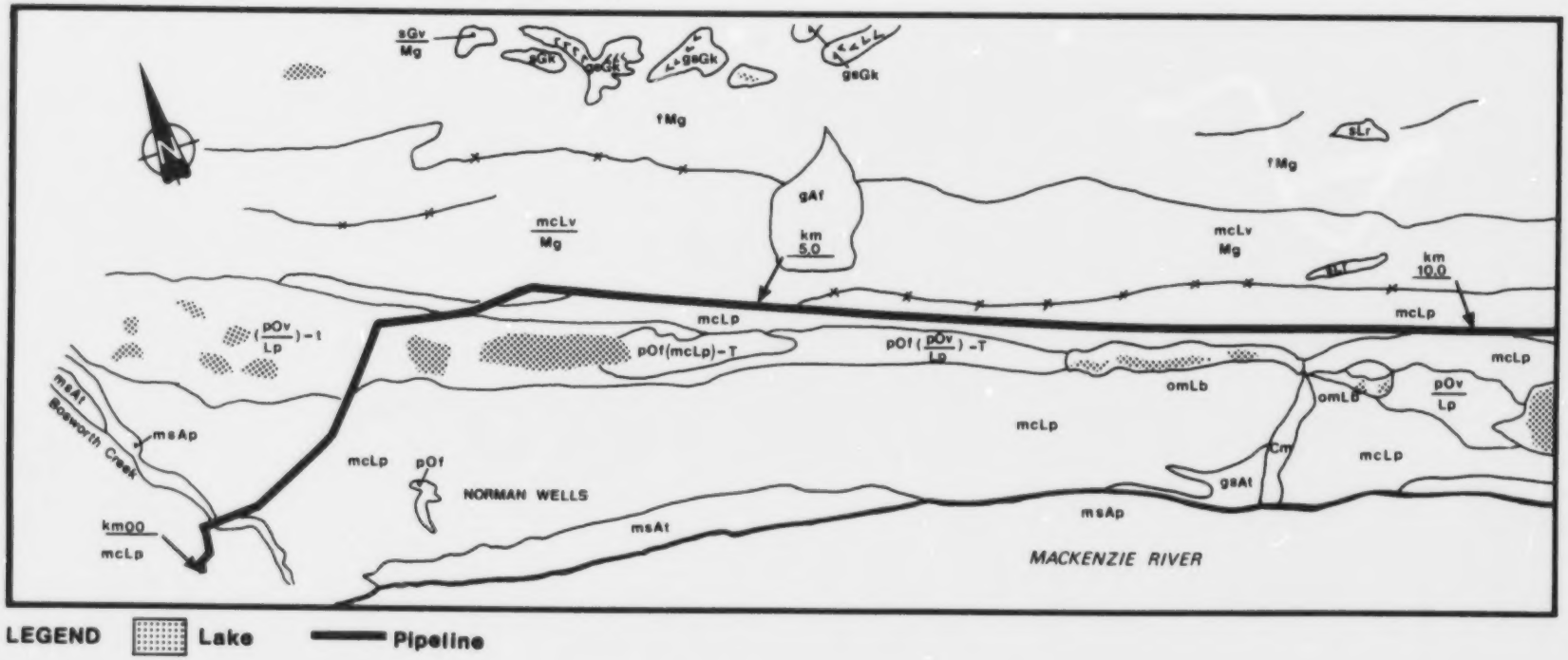


Figure 2-4. Example of terrain-types alignment sheet, Norman Wells area.

Figure 2-5. Pipeline traversing extensive area of organic terrain, south of Fort Simpson (km 561), view south. (23//06/86)

TABLE 2-6: DISTRIBUTION OF MAJOR TERRAIN TYPES, NORMAN WELLS PIPELINE (MODIFIED AFTER KAY ET AL, 1983)

	PIPELINE ROUTE SEGMENT					
TERRAIN TYPE	1	2	3	4	5	6
Alluvial	1.44	6.15	8.02	0.53	2.18	0.00
Colluvial	1.31	3.43	4.80	0.26	0.86	0.00
Eolian	1.36	0.34	0.29	3.46	4.40	0.00
Glaciofluvial	2.88	12.41	6.68	4.80	2.74	0.00
Lacustrine	28.51	39.24	33.60	5.43	9.30	8.77
Lacustrine-Morainal	9.82	22.51	0.00	9.93	1.80	0.00
Morainal	15.64	1.70	25.77	42.27	20.56	14.88
Organic	6.37	2.95	1.44	6.67	31.39	48.63
Organic veneer	18.84	11.27	17.72	26.55	26.76	27.72
Bedrock	13.83	0.00	1.68	0.00	0.00	0.00

Key to pipeline segments:

1. km 0.0 - km 149.5
2. km 149.5 - km 269.3
3. km 269.3 - km 380.4
4. km 380.4 - km 528.8
5. km 528.8 - km 695.9
6. km 695.9 - km 868.3

2.3 PERMAFROST

2.3.1 Permafrost distribution and ground thermal regime

Permafrost distribution

The pipeline route lies completely within the permafrost zone of Northwestern Canada. The exact position of the boundary between the continuous and discontinuous permafrost zones is the subject of some uncertainty and debate, in part because of a lack of agreement on the criteria for its determination, but also because of insufficient data. Brown and Pewe (1973) suggest that the boundary corresponds to location of the -5.0°C mean annual ground temperature isotherm (at depth of zero annual amplitude) and that in Canada this boundary corresponds roughly to the -8.5°C mean annual air temperature isotherm (average annual air temperature measured in a meteorological screen at a height of 1.3 m above the ground). On the basis of this air temperature isotherm, the continuous/discontinuous boundary in the Mackenzie Valley has been placed about 100 km north of Fort Good Hope (Brown and Pewe, 1973; French, 1976; Brown, 1978). The Norman Wells Pipeline thus almost completely transects the discontinuous permafrost zone (Figure 1-1).

Information on the distribution, temperature and thickness of permafrost in the northern regions of discontinuous permafrost based on precise borehole temperature logs is available in the series of reports "Canadian Geothermal Data Collection - Northern Wells" (most recent volume: Taylor et al., 1982). This data base has recently been expanded (Judge et al., 1986) to include information on permafrost thickness available in the literature as well as interpretations of the bottom of permafrost from geophysical logs obtained by the petroleum industry. This ground temperature data collected to date would suggest, using the criteria of -5.0°C mean annual ground temperature, that the boundary between continuous and discontinuous lies further north, in the vicinity of Inuvik.

Studies of the geothermal regime of the Mackenzie Valley, based on measurements in over 30 boreholes, have been reported in Judge (1973 and 1975). These studies suggested that permafrost is widespread in the northern portion of the pipeline route, being generally less than 50 m but not more than 80 m thick. Mean annual ground surface temperatures are generally negative in this region and range from -1 to -3°C. Along the southern portion of the pipeline route, positive ground surface temperatures are more frequently observed; permafrost is generally scattered, at temperatures close to the melting point (between -1 and 0°C) and less than 20 m thick.

Permafrost soils are often ice-rich containing excess ground ice in a variety of forms, including lenses, veins, and irregular ice masses. The pipeline route lies south of the limit of active ice wedge growth. A number of ground ice-related landforms occur along the route, including hummocks, seasonal frost mounds, palsas and peat plateaux (e.g. Van Everdingen, 1978; 1982; Zoltai and Tarnocai, 1975).

Since a more detailed and site specific permafrost distribution along the Norman Wells pipeline right-of-way was desired for thaw settlement design purposes, particularly the location and extent of transitions between frozen and unfrozen terrain, IPL conducted a continuous geophysical survey to map permafrost along the entire route using a 10 m station interval (IPL, 1982e; Kay et al., 1983). The survey indicates qualitatively whether frozen ground is present or absent, but does not necessarly provide information on the total thickness of permafrost when present. Frozen ground was deemed present when at least 3 m of frozen material was detected anywhere down to depths of 10 m, the maximum depth of penetration of the survey.

The interpretated results of this survey are summarized in Table 2-7 and Figure 2-6. In the vicinity of Norman Wells, frozen ground was found to underlie 80-90% of the surface. A major transition occurs approximately half way along the route, near Wrigley, where the percentage of terrain underlain by frozen ground falls from 65-85% to 20-40%. On average frozen ground underlies about 75% of the terrain in the northern half (where finer textured sands and clays are the predominant soil types), and 25% of the terrain in the southern half of the route (where tills and organic terrain are dominant). The slight increase observed south of Fort Simpson reflects a more widespread distribution at the higher elevations of the Alberta Plateau.

In general, as permafrost becomes more sporadic from north to south, the frequency of transitions from frozen to unfrozen ground (interfaces) tends to increase. The geophysical survey revealed that the number of transitions reached values of 8-10 per kilometre at the southern end of the pipeline route. Within this zone therefore, the pipeline passes rapidly between areas of frozen and unfrozen terrain, and transects many patches of warm permafrost close to its melting point.

Review of the characteristics of the ground thermal regime

Temperatures in the ground depend on the surface temperature and on the heat flow from the earth's interior. Temperatures increase with depth in the earth's crust with a geothermal gradient whose average value is approximately 25-30 mK/m, or 25-30°C/km. The upper boundary, the surface temperature, fluctuates both daily and seasonally and these changes propagate downwards with an

TABLE 2-7. SUMMARY OF FROZEN GROUND DISTRIBUTION ALONG THE PIPELINE ROW (source Kay et al., 1983)

CONSTRUCTION SPREAD*	KMP	% OF TERRAIN FROZEN	FROZEN/UNFROZEN INTERFACES	
			AVERAGE NUMBER PER KILOMETER	TOTAL NUMBER
1	0 -149.5	83.7	1.7	259
2	149.5-269.3	66.3	4.3	513
3	269.3-380.4	69.2	3.1	342
4	380.4-528.8	31.6	4.0	592
5	528.8-695.9	16.0	3.2	532
6	695.9-868.3	34.7	9.9	1708

* Spread as delimited for construction planning.

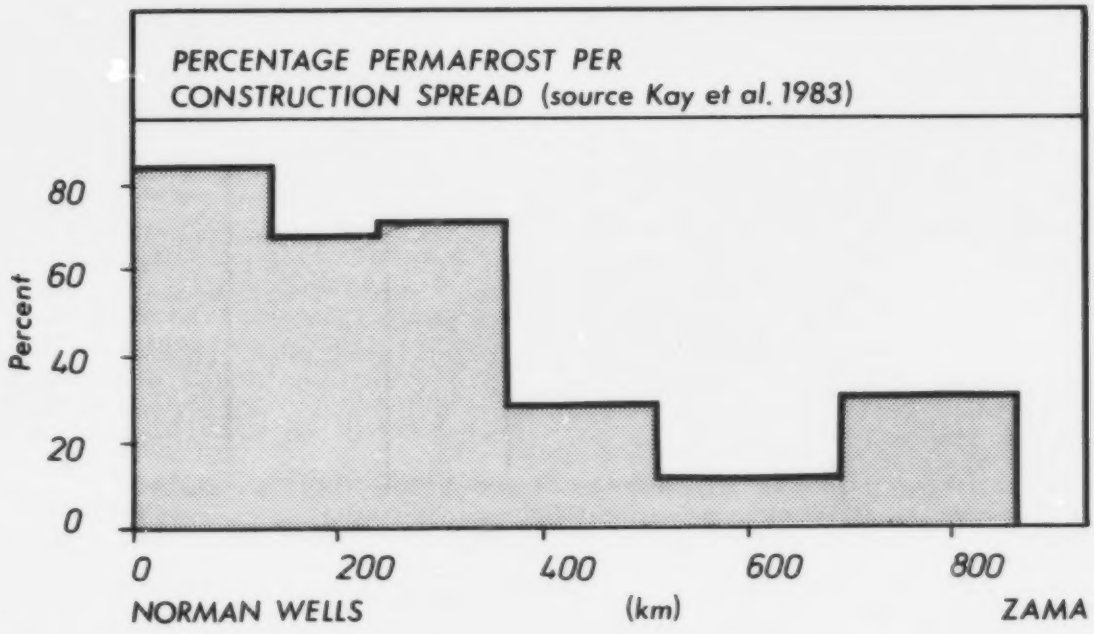


Figure 2-6. Percent permafrost per construction spread.

attenuation in the amplitude and a lag in the phase (shift in timing).

The characteristics of the ground thermal regime, for the particular case of a permafrost environment and for conditions of thermal equilibrium, are illustrated schematically in Figure 2-7. The depth to which the annual surface temperature wave penetrates is known as the level of zero annual amplitude. A mean annual temperature profile can be determined for this zone of annual oscillations, which may extend for as much as 15 to 30 m,depending on the nature of the material. The minimum and maximum temperatures reached at each level define the ground temperature envelope. The layer above permafrost that freezes each winter and thaws each summer is the active layer. Active layer thickness in the Mackenzie Valley (Judge, 1975) varies from 0.3 m beneath peat to 15 m in exposed bedrock.

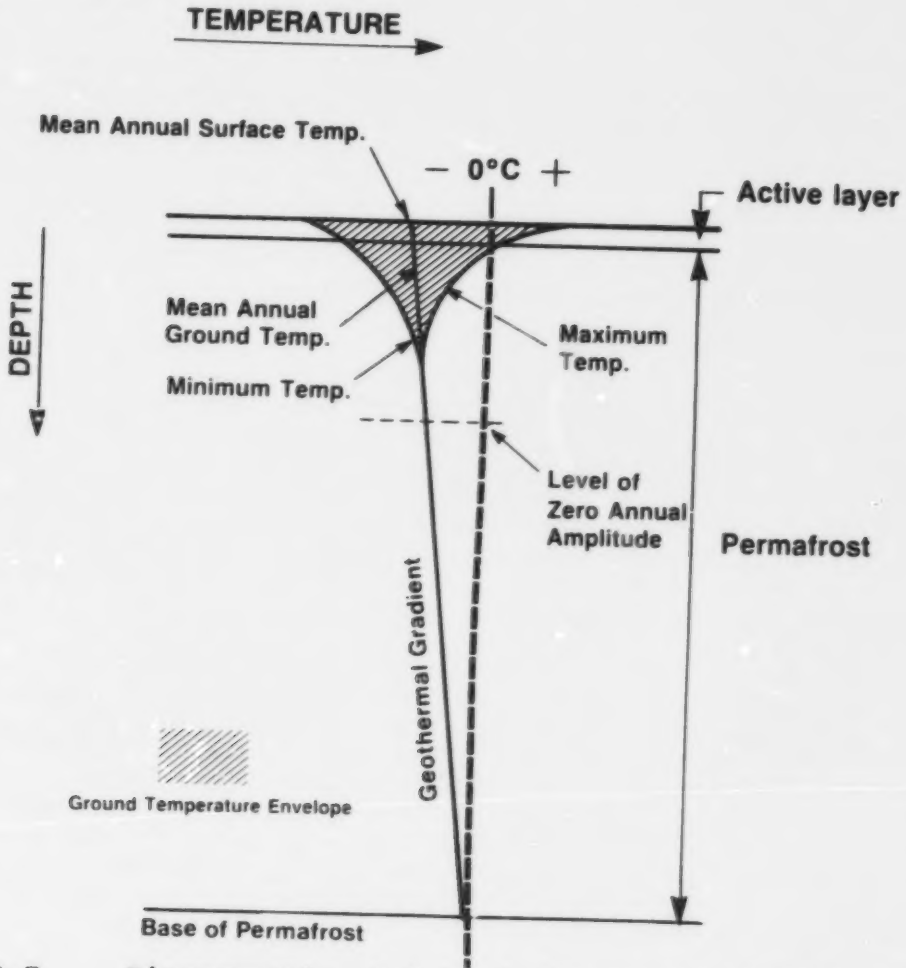


Figure 2-7. Diagrammatic sketch of the ground thermal regime in permafrost.

In studies of the shallow ground thermal regime - depths less than 100 m and generally extending slightly beyond the level of zero annual amplitude - the energy balance at the surface of the earth is of prime importance. This surface energy balance is a function of the interaction of the climate and local microclimatic setting, and determines the ground surface temperature. The sun's radiation is the fundamental factor governing the energy exchange. Surface conditions such as snowcover, wetness, organic layer and vegetation cover also have a major influence on the energy balance.

The soils along the Norman Wells pipeline area, being at temperatures very close to 0°C, are sensitive to slight changes in ground surface temperature since significant changes in soil physical, thermal and mechanical properties occur as soil moisture changes phase. Surface temperature change may result from microclimatic or climatic change, and from natural or anthropogenic surface disturbances (e.g. forest fires, floods, drainage changes, clearing, construction). In ice-rich soils, a slight increase in mean surface temperature may result in an increase in the depth of summer thaw (and perhaps ultimately in the complete degradation of permafrost), the release of excess pore water, and ultimately in ground settlement. In unfrozen frost-susceptible soils, a slight decrease in mean temperatures to below 0°C could create conditions conducive to the formation of ice lenses and frost heave.

The rate at which surface thermal changes (be they seasonal, annual, long term or short term, natural or man-induced) are translated to the subsurface is a function of the thermal properties of the earth materials. The thermal regime in permafrost is often complicated by the presence of water. Heat transfer processes then involve the absorption or release of latent heat, because of the phase change of water. These phase transformations retard the rate at which ground temperatures change. In addition, the thermal properties of frozen wet soils are substantially different from those of unfrozen wet soils. Measured thermal properties of soils in the Mackenzie Valley are reported by Judge (1973) and additional calculated values (based on measured physical properties) by Burgess (1983).

The ground thermal regime is thus both 'dynamic', responding to daily, annual and longer term climatic changes as well as to surface changes, and 'diverse', depending on climate, soil type, organic layer, vegetation cover, water contents and snowcover. The diversity and dynamics of the ground thermal regime are illustrated in Figure 2-8, which shows the ground temperature envelopes at two boreholes 100 m apart along the pipeline route, and Figure 2-9 which plots temperature versus time (at the 1 m depth in the off-ROW borehole) for a permafrost site in the northern section of the route and an unfrozen site in the southern section.

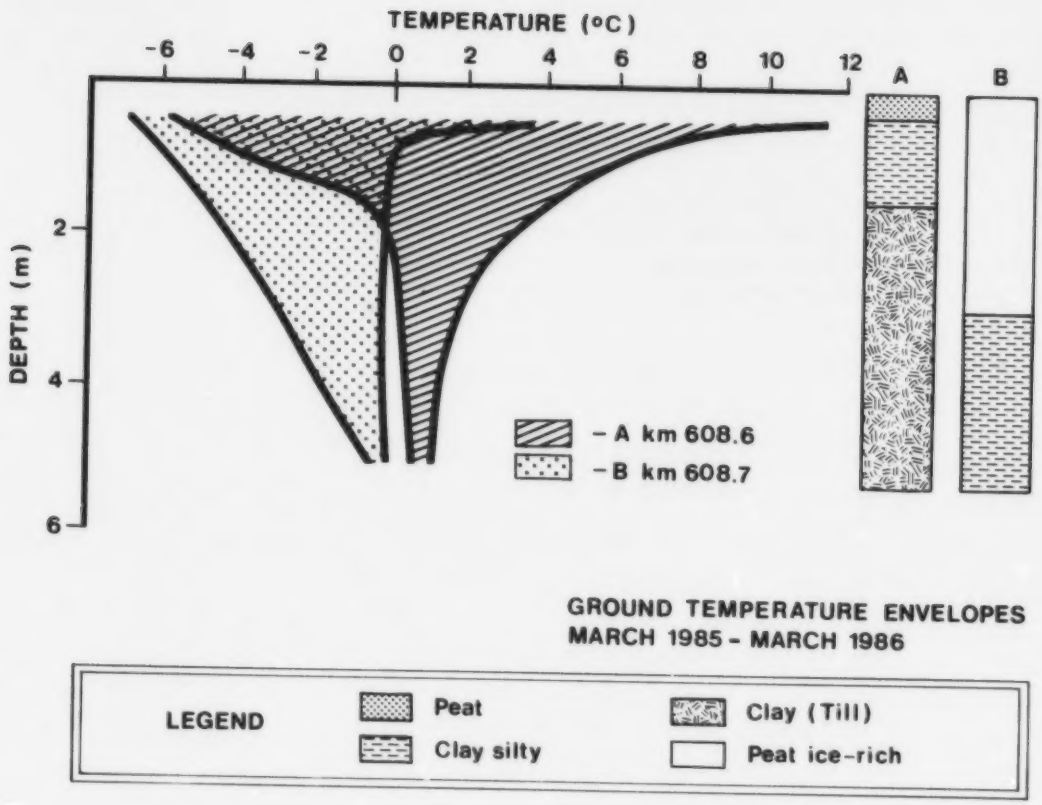


Figure 2-8. Ground temperature envelopes for the period March 1985 to March 1986 at two pipeline monitoring boreholes only 100 m apart.

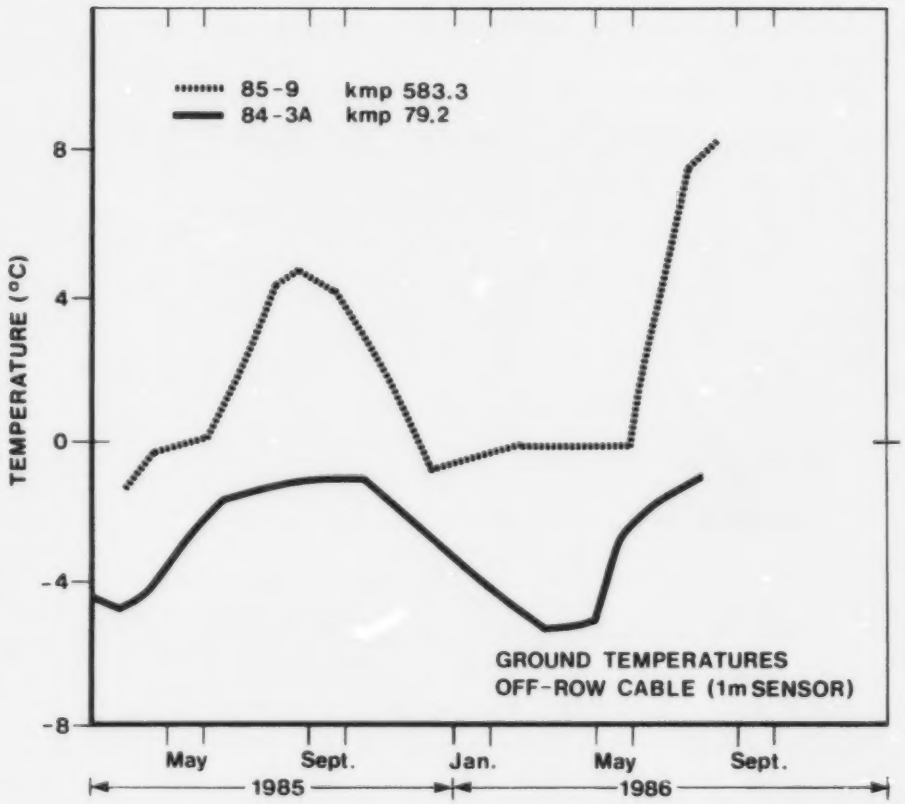


Figure 2-9. Off right-of-way ground temperatures at 1 m depth, for a northern permafrost monitoring site (kmp 79.2) and a southern unfrozen site (kmp 583.3).

2.3.2 Pipeline Project Permafrost Regions

For purposes of the geothermal analysis undertaken by IPL to examine the possible extent of thaw settlement or frost heave associated with the small buried ambient oil line, the pipeline route was subdivided into three regions (IPL, 1980). The regions, essentially delineated on the basis of climatic and permafrost conditions, using work carried out by Canadian Arctic Gas Study Limited during the 1970's, were as follows:

Region 14 - Norman Wells (kmp 0) to South of Police Island (kmp 110): permafrost is widespread.

Region 15 - South of Police Island (kmp 110) to Willowlake River (kmp 376): transition zone with a marked change of permafrost taking place near the Ochre River (kmp 285).

Region 16 - Willowlake River (kmp 376) to Zama Terminal (kmp 866): permafrost is sporadic and generally only occurs where thicker layers of peat are present.

Soil profiles and ground surface temperatures (annual waves) were established for each region for various ROW, permafrost and soil conditions and were used in numerical simulations to determine the maximum possible thaw depths beneath a warm pipe and maximum possible frost advance around a cold pipe, over the 30 year pipeline operation (IPL, 1982f). The use of these regions and the results from the geothermal simulations are discussed in more detail in Chapter 3 and in Volume II, Chapter 4.

2.3.3 Permafrost and Climate Change

Considerable evidence exists, from deep (100 m or more) ground temperature profiles, that during the past century mean surface temperatures in the Mackenzie Valley have increased by up to 3K (Judge, 1975). The effect of a recent increase in mean annual ground surface temperature is seen as a reduction or inversion of the shallow mean annual temperature gradient producing an anomalous curvature in the mean annual ground temperature profile.

In the Macmillan Pass area along the Yukon/N.W.T. border recent analysis of ground temperature data (Seto, 1987) has suggested increases in surface temperature of around 1 K during the last few decades. In northern Alaska widespread warming of the permafrost surface in the range of 2 to 4 K during the last few decades to a century has also been reported from analysis of deep ground temperature profiles (Lachenbruch and Marshall, 1986). The widespread nature of the secular (i.e., over a period of century) warming of the northern ground surface suggests that it can most likely be attributed to changes in climate. Air temperature records in the northern hemisphere generally show a warming trend

from the late 19th century until about 1940 followed by a cooling trend until about 1970 and warming thereafter (e.g. Brown and Andrews, 1982; Brown and Walsh, 1986). Analysis of existing air temperature data from meteorological stations in the Mackenzie Valley yields statistically significant increases of about 1 K in the past 50 years (AES/EMR work in progress). In contrast the arctic coast shows some evidence of cooling over the same period.

Although a change in permafrost temperature might be expected as a result of a secular change in air temperature, the relationship between ground temperature and air temperature is not straightforward. No simple empirical relationship has been found. The ground surface temperature depends on the surface energy balance which is the product of several complex energy exchanges between the air and ground surface involving heat transfer by radiation, conduction, advection and vaporization. Within an area of uniform climate the surface energy balance, and hence the surface temperature, varies widely according to microclimatic factors (e.g. vegetation, organic layer, albedo, snowcover) and lithologic conditions (e.g. soil type and moisture content and phase).

Numerical simulations of the ground thermal regime in the Norman Wells area (Burgess, 1983) showed a wide variation in mean annual surface temperature arising as a result of variations in site wetness and snowcover conditions; for example a variation in snowfall from 0.5 to 1.5 times the climatic normals produced a change of nearly 3°C in the mean annual surface temperature. In permafrost areas factors playing the most significant role in controlling the ground thermal regime are snowcover and the surface organic layer (Goodrich, 1982; Smith, 1986).

Thus the surface temperature response to a climate change in a "uniform climate area" will depend on the effect of this change on the surface energy balance. The response of underlying permafrost to the climate change will in turn depend on the the change in the surface temperature and on the thermal properties of the ground.

Many global change scenarios predict a pronounced warming of the Arctic regions, accompanied by considerable increases in precipitation, over the next several decades (Brown and Walsh, 1986). These changes would be three to five times greater than those experienced by the rest of the northern hemisphere, based on evidence from past arctic climate change. The effects of this or other scenarios on permafrost regions are difficult to predict given 1) that climate models have not yet addressed the detailed reliable predictions at the regional and seasonal level, predictions which are necessary to assessing the impact of global warming on man's activities (Brown and Walsh, 1986), 2) that the response of the surface energy balance is complex, poorly

understood and undoubtedly involves feedbacks, and 3) that local factors strongly influence the ground thermal regime.

Smith and Riseborough (1983) used a numerical climate-microclimate-ground temperature model to analyse the variability in ground thermal conditions and the magnitude and rate of permafrost response to climate change. The study focused on modelling the more sensitive discontinuous permafrost areas using climate and ground conditions from the Whitehorse area. A sensitivity analysis undertaken to indicate the range of possible ground thermal conditions created by variations in local site specific factors was first run for both a normal climate and for a uniformly 2°C warmer climate. Differences in surface temperature due to variation within a single microclimatic factor (e.g. snowcover, wetness) was in some cases greater than that caused by the warmer climate. In a second component of the study simulations of climate change over a 25 year period were undertaken. The results showed that variation in site characteristics (e.g. lithology, snowfall) produced larger changes to the rate of permafrost degradation than variations in details of the climate trend.

The rate and magnitude of permafrost changes due to climate change are not simple to predict, and may or may not be greater than changes due to other disturbances. The ground thermal conditions may be temporarily or permanently buffered from atmospheric climate change, eg. in areas of organic terrain, in areas of increased snowcover, or in ice-rich ground.

The possible changes in permafrost due to climate change (temperature and precipitation) include 1) increased depth of seasonal thaw, 2) long term degradation of permafrost, 3) increases in mass movements on slopes as a result of 1) & 2), 4) changes in the mechanical behaviour of frozen ground (strength and creep are very temperature dependant), and 5) changes in occurrence of ice-wedge cracking. Changes in these processes should be important considerations for both planned and existing northern engineering structures/projects.

2.4 SOIL, VEGETATION AND ECOCLIMATIC REGIONS

Vegetation, soils and landforms of the Mackenzie Valley and pipeline area have been reviewed in the Norman Wells Project Environmental Impact Statement (Esso and IPL, 1980) and in the Beaufort Project Environmental Impact Statement (Dome, Esso and Gulf, 1982), as well as in earlier studies (Leahey, 1947; Day, 1962, 1966 and 1968; Day and Rice, 1964; Tarnocai, 1973). Soils at selected instrumented sites along the Norman Wells pipeline right-of-way are described in Tarnocai and Kroetsch (in prep.).

The pipeline traverses two sections of the Canadian Boreal Forest Region (Rowe, 1959) where the coniferous trees white spruce (Picea glauca) and black spruce (Picea mariana) are common, along with jack pine (Pinus banksiana) in drier sites and tamarack (Larix laricina) in wetter sites. The northern boreal forest section (Upper Mackenzie) extends from Norman Wells southward in a narrow band along the Mackenzie River and south to the Trout River area. The southern section (Hay River) extends south of Trout River into Northern Alberta. Deciduous trees such as aspen (Populus tremuloides), balsam poplar (Populus balsamifera) and white birch (Betula papyrifera) become more common in the south. Major vegetation types of the area also include extensive peatlands (sedge fens and peat moss bogs).

From the broad ecoclimatic region perspective (climate, vegetation, soils, permafrost) established by the Canadian Ecoregions Working Group, the pipeline falls within the low subarctic zone in the north (Norman Wells to Fort Norman) and the high and mid-boreal zones to the south (Ecoregions Working Group, 1989). The high boreal zone occurs from Great Bear River to Willowlake River and again from north of Trout River to Zama (Alberta Plateau, Figure 2-2.) The area between Willowlake River and Trout River is the mid-boreal zone (Great Slave Plain area, Figure 2-2).

Vegetation cover in the low subarctic is predominantly of the open black spruce-lichen type, with white spruce occurring mainly along the rivers and creeks in the valleys. Vegetation cover in the high and mid-boreal zones consists of forest stands with increasingly larger and taller white spruce and balsam poplar in medium to well drained sites. Black spruce predominates on poorly drained mineral soils and peatlands.

3. PIPELINE DESIGN CONCEPTS AND MITIGATIVE APPROACHES

3.1 INTRODUCTION

Several different approaches were applied by IPL to assure integrity of the pipeline, minimize effects of the pipeline on the environment and minimize effects of the environment on the pipeline in discontinuous permafrost. Design concepts included limiting the energy (heat) input into the ground by using a small diameter pipe and initially chilling the oil. The grade of steel and the pipe wall thickness were selected to reduce stress caused by thaw settlement, frost heave, slope instability and seismic activity, and to provide adequate ductility under difficult soil conditions. IPL also developed special designs to ensure the stability of thaw-sensitive slopes. These and other concerns addressed in planning and design of the pipeline were summarized in Table 3-1 (Pick, 1986). Details of designs are presented in Nixon et al. (1984), Pick et al. (1984), Nixon and Pick (1986), McRoberts et al. (1985), Wishart and Fooks (1986), Wishart (1988) and Hanna and McRoberts (1988).

Table 3-1. Concerns addressed in pipeline planning and design (Pick, 1986)

- "public concern regarding social and environmental impacts of construction and operation,
- settlement problems due to permafrost melt,
- frost heave,
- slope stability,
- crossing of two major rivers,
- crossing of 140 water courses of varying sizes,
- frozen, boulder tills,
- shortages of bedding and padding materials,
- very large bogs and fens,
- scarcity of water for hydrostatic testing, and
- problems related to freezing ground temperatures"

IPL's design concepts for limiting the energy input to thaw-sensitive soils and increasing pipe strength represents a significant change from previous pipelining practice. Normally internal pressure determines the grade and wall thickness of pipe. Nixon et al (1984) summarizes these design differences in the paper, "Design of Norman Wells Pipeline for frost heave and thaw settlement" as follows:

- "Location of a buried pipeline in permafrost will result in some degradation of permafrost and will cause differential settlement of the terrain. The magnitude of the differential settlement can be controlled and limited to an acceptable level by designing the pipeline in such a way that it will have a low energy input to the environment.

- The pipe is treated as a structural member that is designed to withstand deformations caused by differential settlement resulting from construction and operation.

- To the extent possible, the pipeline is located on previously disturbed and cleared rights-of-way (seismic cut lines and telephone lines)."

This design philosophy made it possible to simplify field construction procedures and reduce the level of anticipated field design changes. From an engineering perspective, the use of previously cleared rights-of-way is advantageous since some thaw and ground settlement would have already occurred, increasing ground stability. From an environmental perspective, this use reduces the amount of clearing and ground disturbance.

Design parameters for the pipeline included a maximum allowable operating pressure of 9929 kPa (1440 p.s.i.) and a design temperature differential of 36°C (65°F) based on a pipe reference temperature at winter installation of -30°C and a maximum operating temperature of +6°C (Nixon et al. 1984). Design life of the pipeline is 25-30 years. The input oil temperature for the pipeline was expected to be about -2°C, feasible due to the viscosity of the crude oil at Norman Wells. (National Energy Board, specifies overall pipeline design requirements under its Oil Pipeline Regulations, including compliance with the current pipeline industry standard CSA-Z183.)

3.2 ROUTE SELECTION AND CHARACTERIZATION

Three major alternative routes to the one proposed on the east side of the Mackenzie River to Zama were considered. A route on the west side of the river was judged to be less desirable for numerous reasons including poor access, flood-prone streams and more difficult ditching due to gravelly or rocky terrain. A second alternative following the Mackenzie Highway east of Fort Simpson rather than going overland to Zama, Alberta, was considered impractical because it would require additional pipeline and pumping capacity. A more easterly route, east of the Franklin Mountains, was also considered less desirable because of poor access and the creation of new disturbance and access in an area currently not involved in industrial activity.

A prime route was selected and evaluated from environmental, technical (geotechnical,geological and geothermal), socio-economic and cultural (land use, archaeological) perspectives. IPL's basic approach to route selection involved minimizing the length of right-of-way traversing unstable soils, especially in permafrost and adjacent to water crossings, and maximizing location of the route along existing rights-of-way, especially where thaw-sensitive soils were unavoidable. The proposed route was considered a reasonable overall balance considering environmental, technical, socio-economic and cost aspects. The pipeline alignment was mapped on "terrain-typed" photomosaics (1:20,000) in the "Plans, Profiles and Books of Reference" submitted to regulatory agencies in 1982 (IPL, 1982b). A few minor alignment changes were made during construction (IPL, 1985).

3.3 THAW SETTLEMENT

The selection of a small diameter line and the chilling of the oil to near 0°C at Norman Wells were features designed to minimize heat input from the pipeline into the surrounding terrain. The pipeline, thus operating at temperatures approaching the in-situ ground temperatures, was not expected to cause significant thawing of underlying frozen ground. By contrast, clearing of the right-of-way and construction activities were expected to cause permafrost to slowly degrade beneath the right-of-way because of changes to the ground thermal conditions resulting from the removal, disturbance or changes to vegetation and the insulating surface organic layer.

Differential thaw settlement occurring at terrain transitions was of particular concern for pipeline stability. The thaw settlement design conservatively assumed that the differential settlement across a transition would be equal to the total settlement. The key components of the thaw settlement design therefore focused on 1) determining the extent of frozen ground and unfrozen/frozen transitions and 2) quantifying the amount of settlement that could occur over the lifespan of the project.

The procedure and geotechnical analyses undertaken to evaluate the possible thaw settlement are described in two reports "Geotechnical Report on Thaw Settlement Design Approach" (IPL, 1982a), and "Thaw Settlement Design Values for km 0.00 to km 868.30" (IPL, 1982f). The design process involved the collection, examination and integration of several studies, surveys, field observations, data bases and analyses. These steps are outlined briefly below.

1) The terrain units along the pipeline route were reviewed and categorized (for a summary of this terrain typing see Appendix F in IPL, 1982a).

2) A continuous geophysical survey was conducted along the entire route to determine the percentage of each terrain type frozen and the number of frozen/unfrozen interfaces per kilometer of each terrain type encountered (Kay et al., 1983; IPL, 1982e). Permafrost was defined as being present when at least 3 m of frozen ground was interpreted to be in the top 10 m.

3) Laboratory thaw settlement tests were carried out on borehole samples and combined with published thaw settlement data in order to establish relationships between soil moisture content and thaw settlement. Relationships were established for five major soil groups: 1) organic soils (peat and organic silts), 2) fine-grained glacial lake silts and clays (low to intermediate plasticity), 3) fine-grained glacial lake silts and clays (high plasticity), 4) coarse grained soils, and 5) till samples.

4) A computer borehole data bank (3532 boreholes; consisting of existing holes within 5 km of the alignment as well as about 550 drilled by IPL for investigative purposes along the alignment) was set up and relevant subsurface geological and engineering parameters compiled for the subsurface soil units in each construction spread.

5) Two-dimensional geothermal simulations were undertaken to determine the maximum depth of thaw anticipated over the 30 year operation period. A pipe burial depth of 1.2 m and a 30 m right-of-way were selected. Pipe temperatures used in these simulations were determined for each of the climatic regions (described in Chapter 2, section 2.3.2) by selecting the ground temperature at pipe burial depth in the dominant unfrozen soil profiles (coarse grained low moisture content soils which tend to have relatively high soil temperatures in the summer).

   Four geothermal simulations were run for typical soil profiles (determined from the geotechnical data bank), again selecting boundary ground surface temperatures and soil conditions so as to produce relatively high, and hence conservative soil temperatures. Boundary conditions were selected to represent ground surface temperatures for cleared ROW in permafrost (i.e. degrading permafrost). The thaw depth simulations are summarized in Table 3-2 along with the resulting thaw depth predictions (maximum anticipated thaw depth beneath the right-of-way after 30 years operation). Thaw depths used for design purposes are summarized in Table 3-3 according to construction spread (see Figure 1-3 for approximate kilometre locations).

6) Thaw settlements for these design thaw depths were then calculated for every borehole in the IPL geotechnical data bank. The boreholes were divided into layers, according to the five major soil settlement units, and the calculated

TABLE 3-2. GEOTHERMAL SIMULATIONS AND THAW DEPTH PREDICTIONS (IPL, 1982f)

RUN #	SOIL PROFILE DESCRIPTION	CLIMATIC REGION	DESIGN THAW DEPTH (m)
1	low moisture content, till	14 (km 0 - 100)	9.1
2	low moisture content, till/clay	15 (km 100 - 400)	12.2
3	organic veneer	16 (km 400 - 868)	9.1
4	thick organics	16 (km 400 - 868)	6.1

TABLE 3-3. DESIGN THAW DEPTHS FOR THAW SETTLEMENT CALCULATIONS (IPL, 1982f)

CONSTRUCTION SPREAD+	TERRAIN TYPE	DESIGN DEPTH OF THAW FROM FROM GROUND SURFACE (m)
1 (km 0 - 150)	all *	9.1
2 (km 150 - 263)	all *	12.2
3 (km 263 - 377)	all *	12.2
4 (km 377 - 527)	all *	12.2
5 (km 527 - 697)	all *	12.2
6 (km 697 - 868)	all *	12.2

+ spread as delimited for construction planning

* with the following exceptions: i) if terrain type is thick organics, thaw depth = 6.1 m; ii) if terrain type organic veneer over lacustrine plain, ground moraine or eolian deposits, thaw depth = 9.1 m.

TABLE 3-4. DESIGN DIFFERENTIAL THAW SETTLEMENTS (IPL, 1982f)

SEGMENT km	TERRAIN TYPE	THAW SETTLEMENT DESIGN VALUE (m)
0 - 78	all except thick peat	0.80
78 - 440	all except thick peat	0.75
440 - 868	all except thick peat	0.70
0 - 868	thick peat (> 1.2 m)	1.00

settlement for each layer summed to obtain the total settlement for the borehole. The borehole settlements were then sorted by terrain type and construction spread. Thaw settlement design values were established following a statistical examination of the data. This approach focused on the mean calculated settlement beneath the pipe for a terrain unit. A final step involved the application of a correction factor of 0.75 to the predicted settlement. This correction factor was determined following a comparison of predicted settlements and field observations of terrain relief at several sites with permafrost degradation. The design thaw settlements thus established for each pipeline segment are given in Table 3-4.

The thaw settlement design values are considered to represent reasonable mean total and differential settlement of soils below the pipe. It was known from the geotechnical data bank analysis that localized areas might experience greater differential settlement. Seven sites were thus identified for thaw settlement monitoring and included in IPL's geotechnical monitoring program (IPL, 1984). Additional locations, should they arise, would be identified for investigation through IPL's visual monitoring program (an integral part of their geotechnical monitoring program) when differential settlements in the range of 70-80 cm were observed at the surface. Critical distances for differential pipe settlement are about 30 m (IPL personal communication).

One of the recommendations on geotechnical concerns, pipeline integrity and permafrost in the FEARO panel's review of the Norman Wells pipeline project (Duffy, 1981) was to include in the geothermal analysis the possibility of climate change over the lifespan of the project. Although it was recognized that a warming climate might lead to an increase in thaw depth and thaw settlement predictions (and vice versa a cooling climate could increase frost heave predictions), greater uncertainty prevailed at that time as to possible magnitude, timing and direction of climate change. As a result IPL felt that climate change could not be readily addressed in the design but could be addressed in terms of remedial response during operation. An analysis of the possible effects of climate change was not a requirement of the National Energy Board's issuance of certificate (NEB, 1981).

3.4 FROST HEAVE

The possibility of frost advance and heave beneath the pipe was expected to be small on the Norman Wells pipeline, since the pipeline would be operating at temperatures near 0°C (as opposed to several degrees below 0°C) and generally buried within the seasonal freeze/thaw layer. Frost heave was thought most likely to occur within the northern portion of the pipeline route where

the pipeline might traverse several kilometers of cold frozen ground (at temperatures 1 to 2 degrees below freezing on average and possibly reaching -8 to -10°C in the middle of winter) before entering terrain underlain by unfrozen ground. Within this region, the likelihood of frost heave was thought to be the greatest during the first few years of operation. Ground temperatures surrounding the pipe would be at their coldest in these early years, since the thermal disturbance from right-of-way clearing, construction and operation would not have yet penetrated to very great depth.

Differential heave at a transition was a principal concern for pipe integrity, particularly where the pipe was buried at greater depths and the frost bulb might not be part of the seasonal frost layer. This was to be the case for sag bends at stream crossings and some deeper burial overland sections. An evaluation of the frost heave potential of the soil beneath the pipeline was therefore undertaken so as to determine the additional strains imposed on the pipe by heaving across a frozen/unfrozen transition.

The frost heave analysis, reported in Nixon et al. (1984), proceeded as follows. Pipe temperatures following passage through a long stretch of frozen ground were assumed to be equal to the ground temperature at burial depth in thaw-stable permafrost. These pipe temperatures were input into a two-dimensional geothermal program to determine the advance of frost in unfrozen ground. A conservative estimate of the maximum amount of heave that might occur as a result of this frost advance was obtained by using the frost heave properties of the highly frost-susceptible Calgary silt.

Predicted frost heave varied between 97 and 125 mm depending on location along the route. Analyses carried out with 5 cm of urethane insulation around the pipe reduced the predicted amount of frost heave beneath the pipe to 79 mm in the more northerly regions, and 63 mm further south. IPL's post-construction monitoring plan (IPL, 1984a) proposed to instrument four frost heave monitoring sites.

3.5 SEISMIC EFFECTS

In general, seismic considerations had minor effects on design due to low levels of historic seismic activity in the Mackenzie Valley area and the absence of soils susceptible to liquefaction along the route (Nixon et al., 1984). Ground accelerations and subsequent strains were calculated for a design probable earthquake (DPE, associated with a 50 year return period) and a design maximum earthquake (DME, associated with a 100 to 200 return period) in frozen and unfrozen soils in the two seismic zones identified. The strains (DPE, strains reduced 15% from DME) were added to the

loadings from other sources (Nixon et al., 1984) for the pipe stress analysis.

3.6 SOME IMPLICATIONS OF THAW SETTLEMENT AND FROST HEAVE DESIGNS TO ASSURE PIPE INTEGRITY

Assessment of the geotechnical information outlined in sections 3.3 and 3.4 revealed that the structural response of the pipe to loadings caused by differential thaw settlement and frost heave would govern the pipe parameters (grade and wall thickness). The pipe stress analysis outlined in Nixon et al. (1984) involved first the development of a generalized finite element model and then design and sensitivity runs to finalize the pipe parameters. Various loading combinations were examined for different regions along the route; with a detailed analysis of differential pipe settlement, frost heave, localized denting (caused by large boulders), and bends. The esssential results of the pipe stress analysis relating to thaw settlement and frost heave were as follows:

(1) since the depth of cover strongly affects the loading on the pipe subjected to differential settlement, the minimum depth of cover was reduced to 0.76 m from the normal NEB requirement of 1.0 m minimum depth of cover.

(2) since the magnitude of predicted frost heave could not reasonably be accommodated by increasing the pipe wall thickness, IPL proposed to use thermal insulation on the pipe at sag bends in stream crossings.

(3) IPL proposed to increase the pipe wall thickness to withstand predicted differential settlement as given for various pipeline segments. A wall thickness of 6.22 mm (0.245 in) would normally be required ignoring heave or settlement.

0 - 78 km:	7.16 mm
78 - 440 km:	6.91 mm
440 - 868 km:	6.35 mm

3.7 SLOPES

The Norman Wells Pipeline traverses many permafrost slopes, especially north of Willowlake River (km 380), which required evaluation to determine their susceptibility to downslope movement as a result of permafrost thaw. In total over 165 slopes required geotechnical evaluation and design (McRoberts et al., 1985, 1986; Hanna and McRobert, 1988).

IPL identified likely modes of failure (backfill around the pipe, part of slope, whole slope), overall approaches and main mitigation concepts (Pick et al., 1984). The overall approach involved three phases:

(1) design (evaluate stability, establish practical mitigation for instability);

(2) construction (follow specifications to minimize disturbance of sensitive slopes, evaluate/refine designs); and

(3) operation (monitor, especially with respect to geothermal and ground water conditions).

The main mitigation concepts developed as a result of the geotechnical studies and analyses are (a) "prevent thaw", (b) "retard thaw" and (c) "cut back" slopes (Table 3-5). These led to the development of a set of construction guidelines for ice-rich clay, ice-rich till and ice-poor till, the three major generalized types of permafrost soils encountered. The guidelines were based on observed slope performance, field descriptions and laboratory tests (Table 3-6). The most common major groupings of permafrost soils were ice-rich clays and ice-poor tills (McRoberts et al., 1985). Slope guidelines included reducing the width of right-of-way clearing to 13 meters to minimize the depth of thaw on slopes.

In the design phase, three "prevent thaw" slopes were identified in the Wrigley area (km 271.4, 273.5 and 273.6). The north and south slopes of Great Bear River and the south slope of the Mackenzie River are examples of ice-rich till slopes of the "retard thaw" type. The south slopes at both Great Bear and Mackenzie Rivers were cut and insulated.

IPL assessed several methods to insulate slopes including gravel, wood chips, synthetics and thermosyphons (McRoberts et al. 1985). Wood chips were selected because of their availability as a local resource and ease of use in cold weather. Design advantages, disadvantages and solutions are summarized in Table 3-7. A major disadvantage was heat generation due to microbiological activity in the wood chips.

Thermal analyses and pre-construction slope inspections were used to determine thicknesses of wood chips to be used (to 1.5 m). Final judgements on sensitive slopes and on wood chip requirements (thickness and extent) were made by a senior geotechnical engineer during construction. To evaluate performance, IPL instrumented selected slopes (temperature cables, piezometers, and settlement plates) including 17 of the wood chip insulated slopes.

Table 3-5. Slope mitigation concepts (Pick et al., 1984)

Mitigation concepts	Comments
1. Prevent thaw	for highly ice-rich slopes restrict thaw to natural active layer
2. Retard thaw	allow thaw advancement at a controlled rate
3. Cut back	for steep slopes cut back to ensure long term stability

Table 3-6. Slope design guidelines (Pick et al., 1984).[1.]

Soil[2.]	No Mitigation	Mitigation	
		Slope Treatment	Select Backfill[3.]
Ice-Rich Clay (IRC)	< 9° stable	> 18°, cut and insulate	> 4°
Ice-Rich Till (IRT)	< 13° stable	> 20°, cut and insulate	> 7°
Ice-Poor Till (IPT)	< 18° stable	> 18°, cut back depending on height	> 10°

1. Also involves reduction of cleared right-of-way width from 25 m to 13 m to retard thawing.
2. Three major groups of generalized permafrost soils:
   IRC - frozen glaciolacustrine soils with water contents > 25-30% within the zone of thermal disturbance;
   IRT - intermediate class adopted for analysis, some visible ice, higher water (ice) content than IPT;
   IPT - frozen till, water contents typically < 10-15%.
3. Refers to substitution of non ice-rich (select) material for local ice-rich soil when refilling the ditch around the pipe.

Table 3-7. **Design considerations for use of wood chip insulation (McRoberts et al., 1985).**

Advantages	Disadvantages	Solutions
- renewable resource	- heat generation due to microbiological activity	- model heat generation as measured in full scale test fill
- easily accessible supply,	- changing thermal properties with time	- measure thermal properties of wood chips of different ages
- easily rehabilitated if movements occur	- easily eroded by moving water	- control erosion with ditch plugs, cribbing and diversion berms
- easily placed directly on slope without high quality specification	- wood chips do not revegetate easily	
- retains moisture; high latent heat	- possible polluting leachates	
- thermal conductivity close to other insulating materials: wood chips 0.13 W/mK Styrofoam HI 0.03 W/mK polyurethane 0.02 W/mK gravel 2.72 W/mK	- wood chip layer provides only a minor load surcharge and little benefit in improving effective stresses at the thaw line	

3.8 WATER CROSSINGS

Preliminary route selection studies in 1980 identified 166 water crossings of which about 40 were intermittent or dry streams and 94 were small creeks expected to be either dry or frozen at the time of winter construction (IPL, 1982c). Locations of some of the more important rivers are shown in Figure 1-3. Great Bear and Mackenzie River crossings are classed as major; the other rivers from Prohibition south to Harris, plus Jean-Marie and Trout Rivers, are examples of rivers classified as intermediate crossings.

The final design approach involved setting criteria for crossing selection, classifying water courses as major, intermediate and minor (Table 3-8) and conducting field and engineering studies (IPL, 1982c).

Table 3-8. Definitions and factors involved in the selection of water crossings. (IPL, 1982c)

Definitions

Major:	greater than 300 m in width, (Great Bear River, kp 79.0, Mackenzie R. kp 528.0)
Intermediate:	bankfull channel widths between approximately 8 and 300 m
Minor:	generally less than 8 m channel width, little or no channel activity

Factors

line length
proximity of existing cutline
approach slope stability
channel stability
bank erosion
presence of flood plain
proximity of cultural features, including archaeological sites
presence of warm springs
presence of fish spawning, rearing or over-wintering areas
presence of denning sites

Estimates of the magnitude of the 100-year flood were made from frequency analyses of recorded flows, or from a variety of estimating techniques where records were short or non-existent. At the time of planning, Water Survey of Canada had records from seven of the rivers crossed by the pipeline (Table 3-9).

Table 3-9. Rivers crossed by the pipeline having Water Survey of Canada recording stations in 1982.

1. Bosworth Creek at Norman Wells
2. Great Bear River at outlet of Great Bear Lake
3. Big Smith Creek near winter road crossing
4. Willowlake River near the mouth
5. Mackenzie River at Fort Simpson
6. Trout River at NWT Highway No. 1
7. Kakisa River at outlet of Kakisa Lake

Hydraulic analyses were used to define the extent of inundation from a design flood discharge across the channel and flood plain, and regime analyses were used to predict the future behavior of the river near the water crossing.

Estimates of lateral migration over the lifetime of the pipeline were made to determine "sag points" (locations where the pipe is brought up from deep burial beneath the water crossing). Scour and bed degradation conditions were also estimated.

Site specific designs were prepared for 6 crossings in Alberta and 51 crossings in the Northwest Territories (subject to minor revision at construction time). Although straight, stable locations between meander bends (with relatively low potential for scour) were preferred locations,stable approach slopes and presence of existing cleared lines were important factors in final location (IPL, 1982c).

The main mitigative measure with respect to pipe position involved deep burial of the pipe (> 1.5 m) over what was considered to be an adequate width of channel based on a 100-year flood event and other considerations. Most water crossings were constructed in winter over as short a time period as possible to minimize disturbance to fish and fish habitat. Rock rip-rap was placed at the base of some of the streambank slopes to increase slope stability. The ditchline within the water course was backfilled to the original grade of the stream bed with granular material.

3.9 DRAINAGE AND EROSION CONTROL

The three major objectives of drainage and erosion control were (1) maintain pipeline integrity, (2) maintain right-of-way integrity and (3) protect the environment, especially aquatic habitat. The design approach involved consideration of terrain type, slope, drainage patterns, flows, "soil erodibility", "thermal erosion susceptibility", and topography (Pick, 1986).

Hydrologic aspects of the design considered climatic characteristics on the basis of (1) three climatic zones (based on five factors) (2) rainfall intensity using intensity duration frequency characteristic curves developed for three points along the pipeline route (Zama, Fort Simpson and Fort Norman) and (3) a conservative design return event of 50 years (IPL, 1983). High runoff coefficients were developed for permafrost terrain since rainfall storage would be limited to the depth of the unfrozen active layer.

The importance of thermal erosion (erosion of ice-rich permafrost by combined thermal and mechanical action of moving water) was recognized. Designs for drainage and erosion control structures did not take revegetation into consideration for design purposes because it was assumed that about three years would be required before revegetation would be effective in erosion control (IPL, 1983).

The main stability concerns along the Norman Wells Pipeline right-of-way were considered to be due to the thawing of permafrost (IPL, 1982d). Most thaw and settlement and slope instability were expected during the first 5-7 years after construction. Other stability concerns were related to movement and settlement of ice-rich or snow mixed excavated material placed back into the ditch over the pipe, and subsequent channeling of water movement in the ditchline when material settled below adjacent ground levels. Mitigation involved use of select backfill (non ice-rich fill) and placement of elevated mounds of backfill over the ditchline.

Several techniques were used to control surface and subsurface drainage to minimize erosion: these included drainage ditches, diversion berms and ditch plugs (Table 3-10). Some of the problems and solutions to drainage control are reviewed in Wishart and Fooks (1986) and Wishart (1988), as well as in IPL's various annual reports on construction and monitoring submitted to National Energy Board and Indian and Northern Affairs. Figures illustrating plans for typical designs for armoured drainage ditches, diversion berms, mound breaks and ditch plugs are available in Wishart (1988).

Table 3-10. Mitigative measures to minimize drainage and erosion problems.[1]

Surface drainage
Facilitate cross drainage:
- make breaks in the raised backfill mound over the ditchline to prevent training water movement along the ditch line
Water diversion:
- installation of drainage ditches
- diversion berms (sand bags, native soil and geotextile fabric) to direct water off the right-of-way
Subsurface drainage
- ditch breakers or plugs (to reduce water velocity and force water to the surface)
- insulated slopes (to prevent slope erosion)
Monitoring
- weekly (or more often) low level helicopter patrols to identify problems and undertake preliminary remedial measures

1. Wishart and Fooks, 1986.

3.10 REVEGETATION

IPL's pipeline revegetation was undertaken primarily to reduce erosion by decreasing the velocity of surface water movement and by reducing volumes of subsurface water through evapotranspiration (uptake of water by roots and release to the air). Initial design plans for revegetation called for selection of basic seed mixes (Table 3-11) consisting of five to seven species of grasses known to do reasonably well under northern conditions and covering a range of soil and moisture conditions and growth/development rates for short and long term ground cover (Wishart and Fooks, 1986; Wishart, 1988).

The initial plans included seeding of mineral soils only (defined here as any soils where ditching exposed mineral soils) using a relatively conservative application of seed depending on erosion potential of the site (50 kg/ha or 30 kg/ha). A standard fertilizer was used at 250 kg/ha (Table 3-11). Seedbed preparations and initial post-construction seeding took place in winter using hand and vehicle pulled cyclone seeders. Monitoring and remedial seeding, as required, were planned, as part of the mitigative approach.

Twenty revegetation trial areas were established along the right-of-way in 1984 and 1985 in cooperation with the Department of Indian and Northern Affairs to examine recovery of vegetation cover on major terrain types in level areas with low or nil erosion potential. Treatments primarily included seed only, fertilizer only, or neither seed or fertilizer. Other trial areas were established by IPL or government and IPL to look at specific treatments in organic and dune terrain types.

Table 3-11. Initial main broad-based seed mixes used to revegetate the pipeline right-of-way.[1]

Species (Variety)	Percent by weight 1984	1985
Slender wheat grass (Revenue, Common) (Agropyron trachycaulum)	28%	43%
Creeping Red Fescue (Boreal) (Festuca rubra)	20%	27%
Hard Fescue (Durar, Sheep) (Festuca ovina var. duriuscula)	15%	0%
Creeping Foxtail (Common, Garrison) (Alopecurus arundinaceus)	15%	15%/0%
Meadow Foxtail (Common) (Alopecurus pratensis)	0%	0/15%
Reed Canary Grass (Vantage) (Phalaris arundinacea)	12%	9%
Timothy (Climax) (Phleum pratense)	5%	6%
Kentucky Blue Grass (Common) (Poa pratensis)	5%	0%

1. "Interprovincial Pipe Line (NW) Ltd. Norman Wells to Zama Pipeline Revegetation Activities March - April 1984 and February - March 1985' (July 1985).

Fertilizer: nitrogen - phosphorus - potasium blend (17-25-15)

3.11 SUMMARY OF MITIGATIVE APPROACHES

Some of the major overland pipeline and terrain related mitigative approaches used on the Norman Wells Pipeline project are summarized in Table 3-12. These cover planning and operations.

Specific mitigative measures are available in documents prepared by the Company such as the following:

(1) Norman Wells Pipeline. Environmental Protection Plan for winter clearing activities 1982-1983.
(2) Norman Wells to Zama Pipeline. Environmental Protection Plan 1983.
    Volume A. Protection Procedures.
    Volume B. Inspection.
    Volume C. Contingency Plans.
    Volume D. Environmental Regulations and Commitments.
    Volume E. Construction Monitoring.
(3) Oil Spill Contingency Plan. Norman Wells Pipeline Project 1984.
    Volume 1. Response Plan.
    Volume 2. Reference information.
(4) Norman Wells to Zama Pipeline. Environmental Protection Plan 1988. Reference Manual. Operations and Maintenance.

Preparation of an Environmental Protection Plan (EPP) was a new requirement for a Canadian pipeline project. It became part of the NEB Conditional Approval and reflected relevant regulatory requirements of all agencies.

The mitigative measures for environmental protection were an amalgamation of the Company's initial plans, designs and policies and the detailed procedures developed to meet the terms and conditions of various regulatory approvals. In some cases there was considerable variation in opinions as to the actual environmental effects of the project and hence to the appropriate mitigative measure to be applied. It was felt that monitoring should help evaluate the real effects of the project and provide a basis for prescribing mitigative measures for future projects. In some cases the Company did not agree to a particular perceived problem; however, suggested mitigative measures were incorporated into the protection procedures because it was impractical to try to resolve the issue under the circumstances and timing available (Project Co-ordination Committee, 1985).

In IPL's experience (Project Co-ordination Committee, 1985), one of the most significant issues on environmental effects that had to be resolved related to terrain disturbance and the amount of grading which was necessary on the right-of-way. The Company felt that "the flexibility to grade more of the mat to provide a

better working surface, particularly in years of minimal snow cover, was very important to the efficiency and safety of the construction process and resulted in no significant revegetation or reclamation problems" (IPL, in Project Co-ordination Committee, 1985). The effects of the terrain disturbance will be evaluated from environmental and engineering perspectives through IPL and government monitoring programs. In ice-rich soils, removal of the surface organic layer would be expected to contribute to increased thaw depth, surface settlement and possible drainage disruption and/or increased ponding, and the potential for differential pipe settlement. Few problems would be anticipated in thaw-stable soils.

Table 3-12. Some of the major overland pipeline and terrain related mitigative approaches employed on the Norman Wells Pipeline project

- minimize land area used
- use existing clearings where possible
- keep effects to the right-of-way
- use winter construction and winter vehicle access for remedial work
- limit energy input from pipe especially in thaw-sensitive terrain, slopes (small diameter pipe, chilled oil)
- increase pipe structural strength (frost heave, thaw settlement)
- minimize traversing unstable soils
- special designs for unstable slopes (minimize clearing width,insulate, monitor)
- deep pipe burial at water crossings
- insulate pipe at sag-bends (frost-susceptible soils)
- minimize drainage disruption
- implement drainage and erosion controls, including revegetation
- monitor pipeline and environmental conditions frequently
- implement remedial measures in a timely and appropriate manner (helicopter and hand techniques in summer)
- stockpile sandbags at frequent intervals for use in erosion control
- provide appropriate environmental training to staff during construction and operations (Environmental Protection Plans, Environmental Inspectors)
- evaluation of pipeline and environmental conditions frequently, especially at the end of each thaw season
- adjust monitoring requirements and implement remedial actions as appropriate
- practice contingency plans (leak defection, oil spill clean up)
- development of a pipeline pigging system for investigating pipe condition

4. PIPELINE CONSTRUCTION AND OPERATION

Construction and operation of projects in cold regions takes considerable planning, flexibility and ingenuity. Added requirements include adjusting activities to seasonal timetables, coping with cold climate restrictions on applicability of materials, equipment, techniques and work phases, and dealing with peculiarities of permafrost terrain in winter, and especially in summer. To manage the pipeline project, IPL established four groups responsible to IPL for different functions:

(1) Technical Services Management (planning and design)
(2) Construction Services Management (procurement, contracting, inspection)
(3) Northern Development Management (socio-economics) and
(4) Northern Relations Management (government interaction).

Their roles are discussed in Pick et al., 1984.

IPL made commitments to minimize impacts on the environment and communities, and to involve northerners as much as feasible. Under the Environmental Agreement (Appendix D), the Norman Wells Pipeline project is committed to the principle of "minimum practicable environmental and land use disturbance". In permafrost areas the Company also agreed to undertake measures "designed to prevent or reduce significant adverse environmental impacts arising from the thawing or build-up of frozen ground".

The pipeline system (Figure 4-1) consists of three pump stations (Norman Wells, kmp 0; Wrigley Pump Station, kmp 336, and Mackenzie Pump Station kmp 585). The main operations center is located in Norman Wells.

Construction involved building temporary facilities (e.g. construction camps) and permanent facilities (pump stations, remote maintenance bases). Construction activities also involved access roads, shoo flys (travel detour, e.g. around a steep slope), borrow sites, spoil disposal areas, storage/stockpile sites, remote valve sites, timber harvest sites (for wood chip insulation), and other extra work space. (See Appendix A for glossary of pipeline related terms.)

Transportation systems available in the Northwest Territories at the time of Norman Wells Pipeline construction, 1983-1985, included highway, barge, air service and railway (Table 4-1). Major highway constraints included river crossings at freeze-up and break-up and limited winter road access north of Fort Simpson (approximately mid-January to late March). Summer transportation north of Fort Simpson is by air or water. To minimize terrain and environmental disturbance, summer overland off-road travel in the N.W.T. is limited under Territorial Land Use Regulations to terrain

Figure 4-1. Location of the Norman Wells Pipeline and pump stations (kmp 0, kmp 336, kmp 585).

Table 4-1. Transportation systems available in N.W.T. at the time of Norman Wells Pipeline construction, 1983-1985.

Mode	Location	Comments/Constraints
Highway	Mackenzie Highway Liard Highway (via Alberta or B.C.)	all weather access to Fort Simpson except for Liard River crossing (ferry in summer, ice bridge in winter)
	Winter road	Fort Simpson to Norman Wells (all-weather base Fort Simpson to Wrigley) usually open from mid-January to late March, numerous ice bridges required including major rivers (Mackenzie, Great Bear)
Barge	from Hay River to Fort Simpson and north to Norman Wells	normal season: June 15 to October 31
Air Service	Scheduled main (fixed wing) service to Fort Simpson, Norman Wells. Helicopter service available in Norman Wells and Fort Simpson	Community airstrips available at Fort Norman and Wrigley, some other small air strips or lakes seasonally available
Railway	access through Hay River and Enterprise, N.W.T.	

conditions which will support the vehicle without rutting and gouging of the surface. In permafrost terrain this may limit summer overland access to the pipeline easement except where all-weather roads are available. (Summer access would be granted in case of emergency, but the Company would be responsible for any necessary restoration.)

4.1 PROJECT SCHEDULE

Construction of the Norman Wells Pipeline from right-of-way clearing to testing and commissioning took place over three years, with the main overland pipelining taking place in winter. A detailed master schedule for the overall project is given in Pick et al. (1984). Most mainline right-of-way tree clearing was

scheduled from January to March 1983 with the remainder being completed in early 1984 (km 180-347). Overland pipeline construction was scheduled in early 1984 (winter 83/84) for spreads 1, 4 and 6 (Table 4-2), and portions of adjacent spreads if time permitted. The remainder of the spreads would be completed the following winter.

Pump Stations and the crossings of Great Bear River and Mackenzie River were scheduled for construction in the summer 1984. Operation of a short section of pipeline in northern Alberta (approx. 30 km) would begin in 1984. Commissioning of the full Norman Wells to Zama pipeline was planned for the second quarter of 1985.

Table 4-2. Pipeline spreads identified for geophysical surveys and for pipeline construction in the Northwest Territories.

Spread	Geophysical surveys[1]	Construction (NWT)[2]
1	kmp 0 - 149.5	0 - 158.9
2	149.5 - 269.3	158.9 - 263.0
3	269.3 - 380.4	263.0 - 367.0
4	380.4 - 528.8	367.0 - 525.6
5	528.8 - 695.8	527.5 - 698.0
6	695.8 - 868.3	698.0 - 751.1
2 + 3	-	180.0 - 347.0

1. Kay et al. (1983). Spreads for continuous geophysical investigations.
2. Spreads designated for clearing and construction in NWT.

Note: These kilometre locations refer to initial plan locations prior to completion of construction.

4.2 PRE-CONSTRUCTION ACTIVITIES

Pre-construction activities primarily involved the delivery of pipe, equipment, camp facilities and fuels to campsites and storage locations and the clearing of trees from the right-of-way. It involved summer (barging) and winter work.

IPL had an easement width of 30 m for construction, however, it was generally agreed to clear a width of approximately 25 m, unless a larger area was required. Where previously cleared rights-of-way were used, the centreline of the pipeline was

surveyed to be in the center of the previous clearing, and an additional width was cleared to total 25 m (Figure 4-2). Although it was initially intended to hand clear slopes to 13 m, in some cases delaying clearing to just before construction, in practice many slopes were machine cleared to a greater width. Clearing was done in winter and cleared materials were generally burned on the right-of-way.

4.3 CONSTRUCTION ACTIVITIES

The general sequence of activities associated with overland construction involved preparation of the right-of-way for construction traffic (i.e. pack or clear snow; grade ditchline, travel side or other), hauling pipe to the right-of-way and stringing it out adjacent to the pipeline centreline on pipeline skids, bending, welding, inspection of welds, ditching, lowering pipe into the ditch (including inspection of pipe coating, placement of padding, ditch plugs or weights), replacement of native spoil (backfill) from the ditchline or placement of select material over the pipe, testing, "tie-in" pipe sections to each other, cleaning and recontouring, installing drainage and erosion control works, and completing restoration (seed and fertilize). Special sequences of activities were associated with water crossings and slopes, including the placement of wood chip insulation. In general monitoring instrumentation around the pipe was installed prior to pipe lowering. Boreholes for temperature cable installation were drilled just prior to clean-up.

Figure 4-2. Example of a section of pipeline right-of-way using a previously cleared right-of-way (foreground).

The "Norman Wells to Zama Pipeline Plan, Profile and Book of Reference", 64 terrain typed photomosaics of the right-of-way at a scale of 1:20,000 issued in 1982 (IPL, 1982b), also provides the detailed construction data (pipe specifications and quantity, sectionalizing valves, reference drawings, weight type and location etc.), the history of the right-of-way clearing (new or prior clearing), the location of environmentally sensitive areas (e.g. raptor protection areas) and reclamation specifications. The chainage (kilometre location) in the 1982 reference book refers to the plan locations. In December 1985 "As Built" route sheets were prepared based on the chainage locations at the completion of construction (IPL, 1985). The chainages used for this report and for monitoring activities in general refer to the "As Built" chainages, unless indicated otherwise.

Locations along the right-of-way are usually designated relative to the pipeline: north is toward Norman Wells and south is toward Zama. East and west refer to the respective sides of the right-of-way.

The layout of activities on the construction right-of-way is shown in Figure 4-3 using an example from one of the government instrumented monitoring sites. The respective locations of the spoil side versus the travel side of the right-of-way depends on the direction of actual construction. This is relevant to identifying different levels of surface activity and changing surface conditions across the right-of-way, as well as interpreting thermal conditions below the right-of-way. In southward construction the travel side is on the "west" side of the pipe centerline; in northward construction the travel side is "east" of pipe centerline.

Examples of clearing history and width of right-of-way clearing are given in Table 4-3 for government instrumented monitoring sites. Site 84-3A, on the south side of Great Bear River, is an example of a location at the edge of a larger than normal area cleared to provide adequate work space for the construction of the Great Bear River crossing, as well as adjacent to the "shoo fly" or travel detour around the steep upper slope on the south side of Great Bear River. Sites 84-2B and 2C are on the slopes of Canyon Creek (km 19) south of Norman Wells: cleared right-of-way widths here are approximately 21 meters.

Requirements for preparation of the ground surface for ditching and preparation and maintenance of the right-of-way for travel during construction varied. In some of the wet peatland or organic terrain areas as on the southern part of the right-of-way, snow was packed on the surface to increase frost penetration of the ground and improve the ground's ability to support equipment (Figure 2-5). Grading was usually minimal here and centered over pipeline centerline.

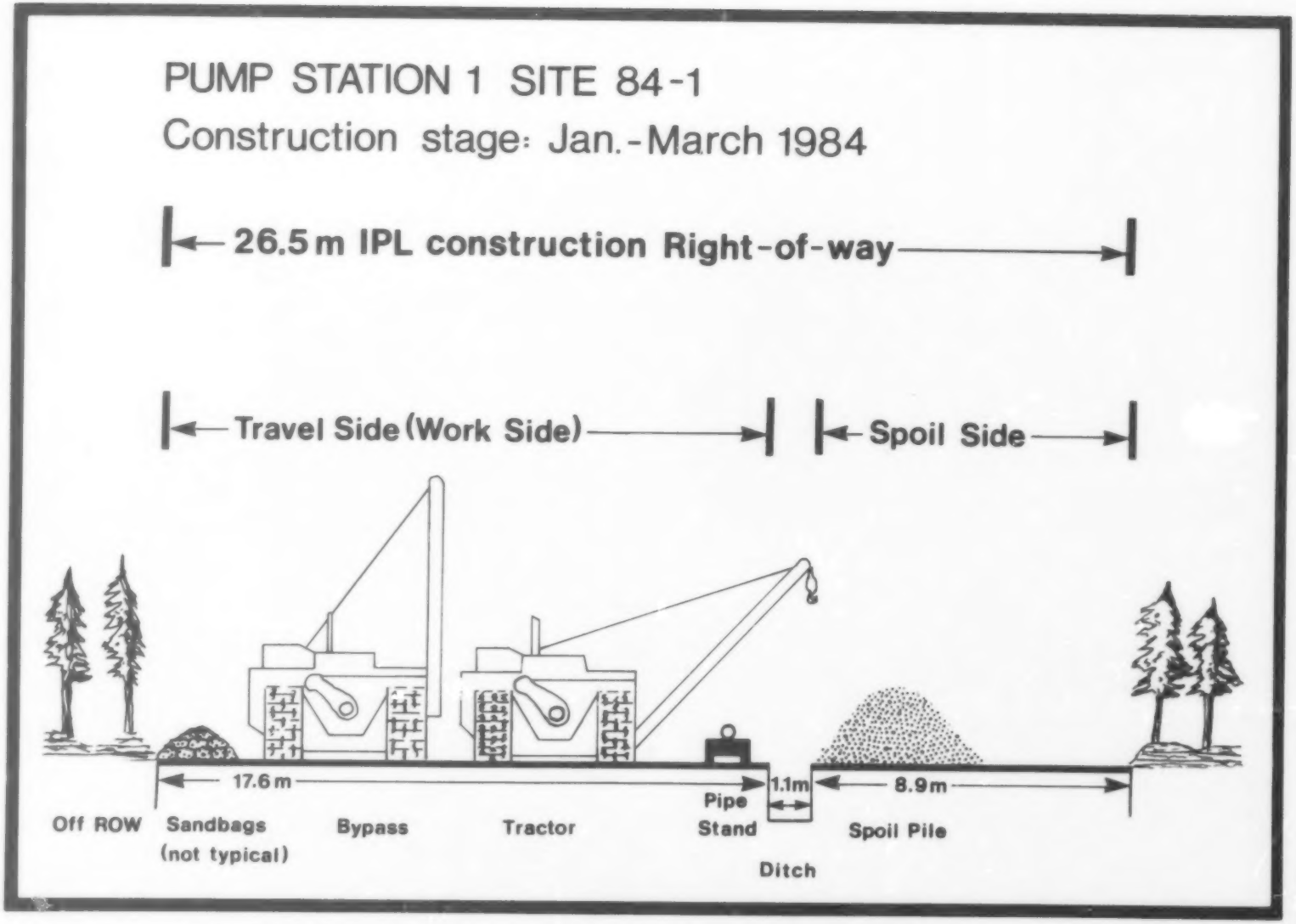


Figure 4-3. Layout of construction on the overland right-of-way, Norman Wells pipeline.

Table 4-3. Right-of-way clearing history and dimensions at government thermal monitoring sites at the time of pipeline construction in winter 1984 or 1985.

SITE[1.] CODE	KMP	PRIOR CLEARED AREA[2.]	WIDTH OF CLEARING (m)	WORK SIDE (m)	SPOIL SIDE (m)
84-1	0.02	no	26.5	17.6	8.9
84-2A	19.0	yes	25.1	14.3	10.8
2B	19.3	yes	21.4	11.2	10.2
2C	19.6	yes	21.7	11.0	10.7
84-3A	79.2	no	67.4	15+	10
3B	79.4	no	16.3	10.7	5.6
85-7A	271.2	yes	25.5	16.9	9.5
7B	272.0	yes	25.2+	14.2	13.0
7C	272.3	no	24.3	14.3	10.0
84-4A	478.0	no	21.4	15.5	8.6
4B	478.1	no	24.5	14.8	9.7
85-8A	557.8	no	25.9	12.3	13.6
8B	558.2	no	24.8	13.0	11.8
8C	558.3	no	23.6	12.25	11.35
85-9	583.3	no	23.1	14.3	8.8
85-10A	588.3	yes	26.7+	17.5	9.2
10B	588.7	no	26.3	17.5	8.6
85-11	597.4	yes	25.7+	14.8	10.9
85-12A	608.6	no	25.7	15.8	9.9
12B	608.7	no	24.8	15.0	9.8
84-5A	783.0	no	25.2	15.3	9.9
5B	783.3	no	26.0	14.2	11.8
84-6	819.5	no	25.0	15.0	9.0

1. Sites 7B, 10A and 11 are partly within or adjacent to 1982 helipad clearings for geotechnical boreholes. Sites 2A, 2B, 2C and 7A were previously cleared in the 1960's.
2. Cleared primarily refers to tree removal although it may also include other disturbance to the surface (e.g. removal of ground vegetation or organic material).

In other areas of organic terrain or terrain in general where surfaces were irregular, hummocky, or abrupt (e.g. edges of a peat plateau) the surface was graded to a more smooth contour to facilitate safe ditcher and equipment travel. The extent of surface grading was influenced by the extent and duration of travel requirements, the timing and amount of snow prior to or during use, and a variety of other factors including water (ice) levels. In most cases grading that involved removal of part or all of the surface organic layer was restricted to the ditch area and travel area, although occasionally it extended across the tree cleared right-of-way. IPL made a commitment to limit traffic on the public winter road: this contributed to an increased requirement for a better travel surface on the pipeline right-of-way. In the Norman Wells to Fort Norman area, to maintain better access most of the right-of-way surface was graded and water was sprayed onto the travel surface. Whether the extent of grading has any adverse effects in ice-rich terrain related to surface settlement or differential pipe settlement remains to be determined and evaluated.

Figure 4-4 shows the timing and direction of main overland construction activities in the winters of 1983-84 and 1984-85. Wheel type ditchers were used to excavate the ditch over as much of the pipeline as possible. Large 750 hp Arctic Ditchers were used on the northern part and smaller 250 hp Barber-Greene ditchers were used on the southern part of the right-of-way, between Wrigley Pump station and Zama, Alberta (Figure 4-5). In areas with boulders, D9 size caterpillars with ripper teeth were used to dislodge boulders and backhoes were used to excavate materials (Figure 4-6). In some cases blasting had to be used to dislodge boulders. The ditch was generally about 110 cm wide and about 100 to 120 cm deep except for deeper burial sag bends below water crossings.

The ditch was backfilled using native spoil or select materials. The largely unconsolidated, frozen material, partly mixed with snow and/or ice, was piled in a raised mound (roach) over the pipe and ditch area to allow for subsequent thaw and consolidation. Breaks were made in the mound at intervals to allow cross drainage. Unstable excavated ditch spoil not used over the pipe was disposed in push-outs (small clearings adjacent to the right-of-way) or in other special designated spoil disposal areas.

Stabilization of thaw-sensitive slopes involved placement of an insulating layer of wood chips to maintain slope integrity (55 slopes, Table 4-4). Tree harvest areas were identified and selectively cut (1) to use trees 15-20 cm in diameter and (2) to avoid aspen and birch as much as possible due to their susceptibility to heat generation. Trees were cut with a caterpillar with hydraulic shears (feller/buncher) or by hand, skidded to a mobile wood chipper at the harvest site, chipped, and the wood chips were trucked to the slope. Where high water was

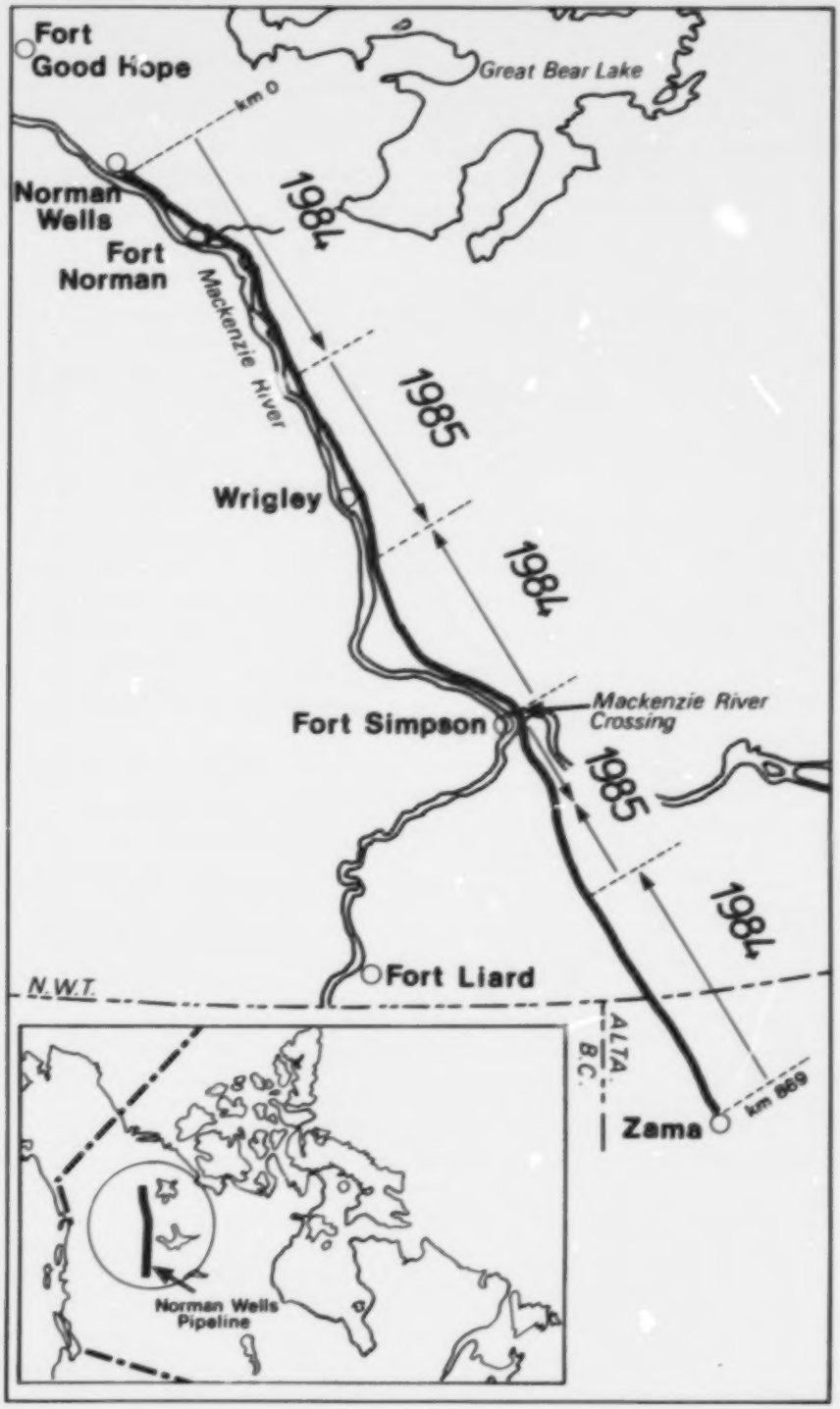
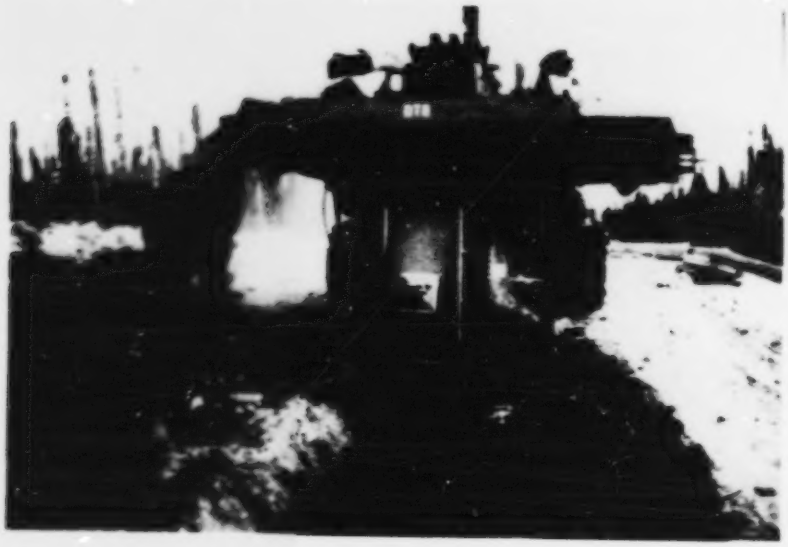
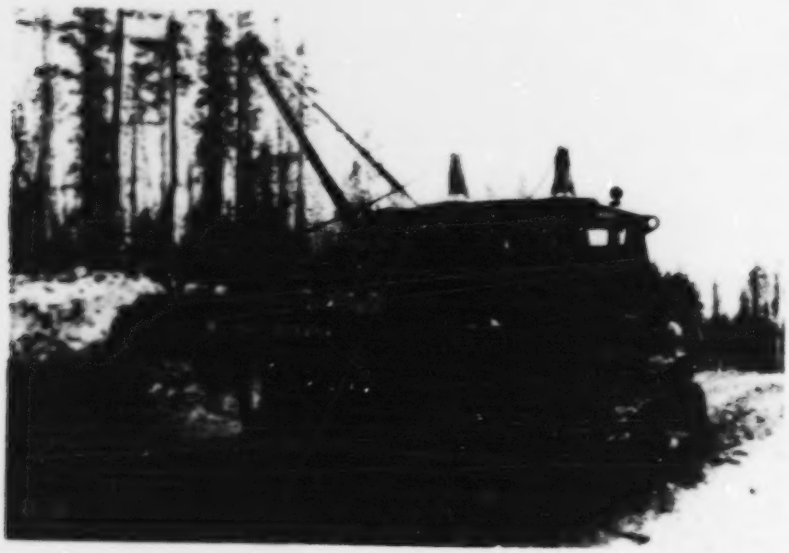


Figure 4-4. Norman Wells to Zama pipeline construction spreads showing and timing of main overland pipeline construction.

Figure 4-5. Wheel or rotary type ditchers used in construciton of the Norman Wells pipeline.



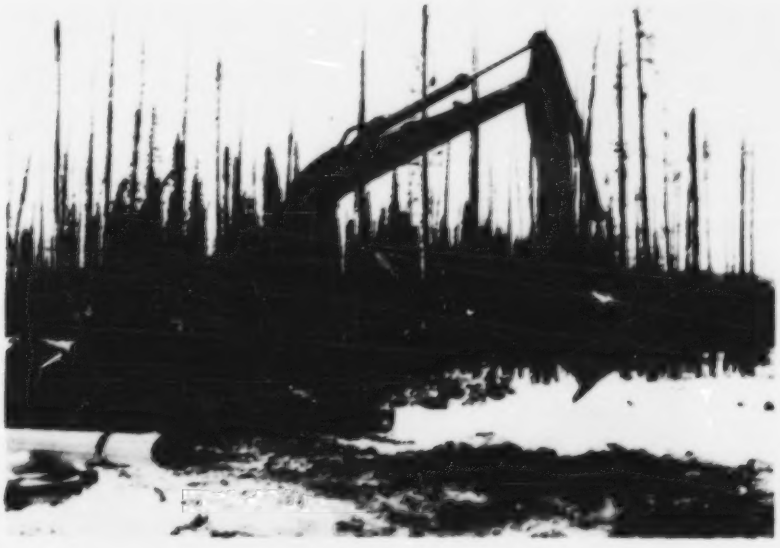
a) Special 750 horsepower Arctic Ditcher used on the northern part of the pipeline (Norman Wells to kmp 336).



b) Lighter Barber Greene ditcher used on the southern part of the pipeline (Zama, Alberta to kmp 336).

Figure 4-6. Large caterpillars and backhoes used to dislodge boulders and excavate the ditch in bouldery terrain.

a) D9 caterpillar with ripper used to loosen ground and dislodge boulders where wheel ditchers could not be used, e.g. ground moraine or till terrain. (27/01/84)



b) Backhoe excavating ditch at Blackwater crossing, km 225. (01/02/85).

Table 4-4. **Thaw-sensitive slopes on the Norman Wells Pipeline insulated with wood chips.**

Slope/Name[1] No.		Location (kmp) (start)	Slope/Name No.		Location (kmp) (start)
1	Bosworth Ck.N	0.3	63	Steep Ck. S.	194.9
2	Bosworth Ck.S	0.4	66	Blackwater R.N	224.4
3	Canyon Ck. N	19.2	66	Blackwater R.N	224.8
4	Canyon Ck. S	19.4	71	Unnamed Ck. N	264.2
7	Francis Ck. N	23.0	73	Unnamed Ck. N	271.4
11	Helava Ck. N	25.6	74	Unnamed Ck. S	271.6
12	Helava Ck. S	25.7	75	Unnamed Ck. N	273.5
14	Christina Ck. S	26.6	76	Unnamed Ck. S	273.6
16	Prohibition Ck. S	32.3	77	Unnamed Ck. N	275.5
28	Gt. Bear River N.	78.4	78	Unnamed Ck. S	275.6
29A	Gt. Bear River S.	78.8	79	Unnamed Ck. N	279.0
29B	Gt. Bear River S.	79.2	80	Unnamed Ck. S.	279.3
30	Unnamed Ck. N.	84.4	82	Ochre River S.	286.6
31A	Unnamed Ck. S.	84.5	84	Unnamed Ck. S.	311.7
32A	Slope N.	93.2	86	Unnamed Ck. S	313.1
32B	Slope S.	93.3	87	Unnamed Ck. N	313.5
33	Unnamed Ck. N.	94.1	88	Unnamed Ck. S.	313.6
34	Unnamed Ck. S.	94.2	89	Unnamed Ck. N.	317.0
35	Unnamed Ck. N.	103.1	91	Unnamed Ck. N.	317.9
36	Unnamed Ck. S.	103.2	92	Unnamed Ck. S.	318.1
44	Unnamed Ck. N	133.6	96	Unnamed Ck. S.	320.6
45	Unnamed Ck. S.	133.7	98	Smith Ck. N.	325.1
47	Little Smith Ck.N.	159.5	99	Smith Ck. S.	325.3
48B	Little Smith Ck.S.	160.1	109	Unnamed Ck. S.	351.9
55	Unnamed Ck. S.	182.2	112	Riv.B.T. Mtn. N	352.3
61	Unnamed Ck. S	191.2	123	Unnamed Ck. N.	403.7
62	Steep Ck. N.	194.4	123A	Unnamed Ck. S.	403.8
			142	Mackenzie R. S.	529.6

1. Abbreviations: Creek (Ck), Great (Gt), North (N), South (S), River Between Two Mountains (Riv.B.T.Mtn)

expected to displace wood chips, a protective wooden cribbing was placed at the bottom of the slope. Truck loads of wood chips were dumped onto the slope and pushed into position with a small tractor/dozer following design verification by a geotechnical engineer (design thickness up to approximately 1.7 m). Seventeen of the wood chip slopes were instrumented with temperature sensors (thermistors) and piezometers: these included representative slopes and ones with maximum thaw-sensitivity.

IPL evaluated problem drainage in the 1984 construction areas and redesigned some of the erosion control methods (Wishart and Fooks, 1986). In 1985 more emphasis was placed on ditch breakers to prevent flow of water in the ditchline and on improving the alignment of ditch breakers to the surface berms. Problems arose when berms settled into the ditch as the backfill thawed and settled, or where the right-of-way surface settled. More emphasis was placed on trying to prevent surface water from flowing down slope under wood chip insulation. More frequent caches of sand bags were stockpiled (approximately 2 km intervals) for ready helicopter transport to problem locations during the summer.

Reclamation activities, defined here as "those activities which will promote the establishment of a rapidly forming, self-sustaining and long-term vegetative cover on disturbed lands" (IPL, Nov. 1983), emphasized priority treatment (e.g. site preparation, assisted revegetation) on highly erodible areas. Less treatment was given to areas of low erodibility. Assisted revegetation was not planned for organic terrain: organic terrain was not expected to be an erosion problem.

Seed and fertilizer specifications were shown on the alignment sheets. In areas of low erodibility (areas with slope gradients of less than 8 percent) and little surface disturbance, applications of seed and fertilizer were limited to a 10 m width centered over the pipe centerline. The full width of the cleared right-of-way was seeded in areas with moderate to high erodibility. Main overland pipeline construction areas were seeded in March 1984 and 1985 following clean-up and other erosion control work. Seed mixes used initially are given in Table 3-11. Further details are available in Wishart and Fooks (1986), Wishart (1988), IPL (1988b), Boreal Ecology (1989a and 1989b) and Hardy BBT (1989).

The Construction Services Management group included up to 75 inspectors to provide quality control during construction, including adherence to IPL's Environmental Protection Plan. IPL conducted a 100% radiographic examination of welding, an independent audit of weld quality and an internal pipe survey to identify dents, buckles and ovality (Pick et al., 1984). To allow ease of welding at low temperatures IPL used a low sulphur, "high energy" steel (Pick, 1986).

After completion of construction, the pipeline required strength and pressure testing. The testing medium prescribed at the time, according to the CSA-Z183 code, was liquid and, wherever practical, restricted to water (Smith and Pick, 1988). NEB Oil Pipeline Regulations also required that the test be conducted over 24 hours. Since this presented problems under conditions of northern winter construction, IPL investigated alternative techniques and proposed using pneumatic air testing. Smith and Pick (1988) review concerns, procedures and results of air testing. IPL obtained approval for use of air pressure testing and the

current Canadian Standards Association Z183 code accepts air pressure testing subject to specified maximum pressure limitations and a minimum of a 24 hour leak test hold period.

Filling of the pipeline commenced in March 1985, a few weeks ahead of schedule. Main overland pipeline construction had completed more pipe laying than expected in 1984 and the remaining sections (km 190-336,528-650) were completed in early 1985. The National Energy Board granted Leave-To-Open for the Norman Wells Pipeline on April 17, 1985.

The areas of federal crown land used under easement and temporary land use permits for the construction of the Norman Wells Pipeline through September 1985 totalled 2,597 hectares, of which the major portion consisted of right-of-way utilization (Table 4-5). These figures include previously cleared land as well as newly cleared land. The calculation for the right-of-way reflected the 25 m cleared area, rather than the 30 m under initial easement (Total "as built" length of the pipeline is 869 km, 751 km are in NWT). The easement has now (1988) been reduced to 20 m: IPL has title to a 20 m pipeline right-of-way and to the area occupied by the two pump stations formerly on federal crown land. The latter easement (approximately 1500 ha) corresponds more closely to the original estimate of 1400 ha for pipeline and facilities (ESSO-IPL, 1980); whereas the total area involved during construction through 1985 was about 2600 ha or about double the area estimated for facilities alone.

Table 4-5. Areas of federal crown land used under easement and temporary land use permits in the construction of the Norman Wells Pipeline in N.W.T.[1]

Type of use	Area (hectares)	
Right-of-way	1,796.83	
Timber harvest sites	462.27	
Access roads/shoo flys	150.87	
Campsites	60.69	
Borrow Sites	42.94	TOTAL:
Spoil disposal areas	28.22	
Extra work space	17.38	2,597.43
Remote valve sites	11.38	
Storage/stockpiles sites	8.02	
Airstrip	7.26	
Truck turnarounds	6.40	
Air testing sites	5.17	

1. From "An Environmental Review", Land Resources, INAC in Project Co-ordination Committee (1985). This includes areas used through September 1985.

Wood chip harvesting involved five timber permits for a total of 26 sites ranging in size from 0.2 hectares to 150 hectares. Quarrying involved 26 quarry permits for granular and borrow material from 51 sites (total = 381,404 yd^3 of sand, gravel, rock and clay). The total of 381,000 yd^3 (292,000 m^3) is less than the borrow material requirements estimated at the conceptual stage (426,000 m^3; EIS, ESSO-IPL, 1980).

For the purposes of this report, events occurring after April 18, 1985 will be considered part of the operations and maintenance phase of the pipeline project. From IPL's perspective, some aspects of activities through winter 1987-88 are considered to be part of the construction phase and other aspects are part of the operations phase.

During pipeline operations from fall 1985 through October 1988, 78 ha of land have been used under land use permits, primarily involving re-use of areas for access to the pipeline right-of-way, and 248,235 yd^3 (189,900 m^3) of borrow material (Land Use Permits N85P405, N85P406). The total amount of granular and borrow materials used for the project through October 1988 is 629,639 yd^3 (482,000 m^3): 61% of the total was used during construction and 39% during maintenance work from fall 1985 through fall 1988.

4.4 OPERATIONS AND MAINTENANCE

Official operation of the Norman Wells Pipeline began April 18, 1985. The control center for the pipeline is based at the pump station in Norman Wells, where the master computer (and back-up computer) is located. Figure 4-7 shows the starting point of the Norman Wells Pipeline. The Pump Stations and all remote control valves and pump stations are linked by microwave to the master computer. The pipeline system is also linked to computers in Edmonton. IPL has full time staff in Norman Wells and Fort Simpson and one part-time staff member at Wrigley.

Maintenance equipment is located at the Pump Stations, (km 0, 336, 585), at Remote Maintenance Bases (Little Smith Creek, km 162; Kakisa River, km 732; and Camsell Bend - Mackenzie Highway km 447) and at IPL facilities at Fort Simpson. Oil spill clean up equipment is located in trailers along the right-of-way. To ensure that effects of spills resulting from line rupture are minimized, sectionalizing valves are at a spacing not exceeding 30 km (NEB Pipeline Regulation). Valves, which include both remotely operated ones (20) and manual ones (28), were located to minimize spill effects in sensitive areas. IPL conducts safety checks on the leak detection system.

Figure 4-7. Aerial photograph (no. A27228-259, 22/10/87) showing the start of the pipeline.

A: Norman Wells Pump Station
B: EMR/INAC monitoring site (84-1)
C: Bosworth Creek wood chip insulated slopes
D: ESSO flare stack (operational since 28/11/84)

One of the unique aspects of the Norman Wells Pipeline project is the transport of oil which has been chilled at adjacent Esso Resources facilities before delivery to IPL's Norman Wells Pump Station. IPL monitors the oil temperature as it enters the Norman Wells Pump station. Pipe thermistors are also located at 37 other locations along the pipe to check operating temperatures (23 of these are at government-IPL instrumented sites). Thermocouples were also added to the pumping system to check the amount of oil heating occurring as a result of pumping, and pumps were changed to reduce the heating effects on the oil. If there are problems in delivery of chilled oil, IPL may shut down the pipeline. There may also be fluctuations in initial oil temperature related to changing of chillers or to volume and pressure changes.

The Norman Wells Pump Station normally pumps at or near maximum operating pressure (731 kw pumps). The next highest level of operating pressure (561 kw pumps) is the Mackenzie Highway Pump Station (km 585) and the third level (245 kw pumps) is the km 336 Wrigley Pump Station (Pick et al., 1984).

During the first year of pipeline operation the average volume of oil moved from Norman Wells was 3452 cubic metres per day (m^3/d) or approximately 21,700 barrels per day (b/d, Table 4-6). This increased to an average volume of 4147 m^3/d (26,100 b/d) in year 3 of operation. The peak monthly oil movement for the first three years of operation occurred in April 1988 (4623 m^3/d or 29,100 b/d). When moving higher volumes of oil, both pumps at the Wrigley Pump Station may be operational (since 1987). By the end of 1988 IPL was frequently pumping about 5000 m^3/d or 32,000 b/d).

Table 4-6. Oil movement from Norman Wells, Norman Wells Pipeline

Operation Year	Dates	Average Volume Oil Moved		Average Volume Peak Month
		Cubic Metres per day (m^3/d)	Barrels per day (b/d)	(m^3/d)
1	18/04/85 - 17/04/86	3452	21,700	-
2	18/04/86 - 17/04/87	3767	23,700	4203
3	18/04/87 - 17/04/88	4147	26,100	4623[1]
4	18/04/88 - 17/04/89	4643	29,200	4763

1. Peak month of oil movement was November 1988. Data supplied by IPL.

To meet their commitment to a policy of environmental protection designed to minimize any potential impacts due to pipeline operation, IPL has undertaken the following:

(1) maintain a current Environmental Protection Plan,
(2) maintain current Oil Spill Contingency Plans, Hazardous Material Contingency Plans and General Contingency Plans,
(3) conduct environmental training sessions with all field staff,
(4) provide environmental orientation to new employees, contractors and visiting staff,
(5) implement appropriate environmental protection procedures in a timely and efficient manner and
(6) ensure management responsibility to monitor adherence to environmental policy and regulatory requirements.

Regular helicopter line-patrols (at least once/week) are made to identify any environmental or geotechnical problems, including checking sensitive slopes (Table 4-7) and water crossings. If

Table 4-7. Other sensitive slopes along the Norman Wells to Zama Pipeline.[1.]

Slope #	Name	Location (kmp)
8	Francis Ck. S	23.1
13	Christina Ck. N.	26.5
18	Vermillion Ck. S.	42.6
22	Norman Range	65.6
24	Slope	67.6
27	Great Bear River N.	77.8
50	Seagram Ck. S.	168.1
52	Saline River N.	179.7
53	Saline River S.	180.2
54	Unnamed Ck. N.	183.1
64	Unnamed Ck. N.	196.9
65	Unnamed Ck. S.	197.0
81	Ochre River N.	285.8
121	Willowlake R. S.	381.3
141	Mackenzie R. N.	528.0
142A	Mackenzie R. S.	530.0
144	Manners Ck. S.	538.3
146	Slope	541.7

1. These slopes, in addition to the ones with wood chip insulation (Table 4-4), have a high potential to erode due to a combination of steepness, material type and ice content (IPL - Environmental Protection Plan. Reference Manual - Operations and Maintenance, 1988a).

problems are identified, they are usually inspected on the ground and remedial work may be undertaken immediately during the patrol, depending on the nature of the problem (i.e. minor drainage or erosion control). If more work is needed, helicopter-supported remedial work is generally undertaken in summer by hand or technical advice is sought. If larger equipment is required, temporary mitigative measures may be carried out in summer and the remainder of the work completed in winter. A variety of tracked vehicles are kept at Remote Maintenance Bases and Pump Stations for emergency winter or summer work or for regular maintenance work primarily in winter (Figure 4-8). Boats are available for summer work. Figure 4-9 and subsequent photographs of work at Seagram Creek (Volume II, section 5.2) show examples of equipment used for summer (thaw season) remedial work.

In 1987 total plant cover averaged 72% on areas first seeded in 1984 and 55% on areas first seeded in 1985 (Boreal Ecology, 1989a). Of the total plant cover about 20 to 30% was attributed to litter. Of the living plant cover it was estimated that about two-thirds was seeded grasses and one-third native vascular plants. Based on air photo interpretation it was concluded that most of the pipeline route (88%) has good vegetation cover in August 1988; however overall the cover had only increased by 4% since 1986 (Hardy Associates, 1986; Hardy BBT, 1989). IPL has concluded that revegetation of the pipeline right-of-way has not been problematic in the short term: substantial cover was produced in the first year after construction using primarily winter seeding without special seedbed preparation and using fertilizer and a seed mix with a broad species composition (IPL, 1989b; Boreal Ecology, 1989b). This revegetation treatment reduced encroachment of native species. Further research should address the relative role of native and seeded species in acheiving long term erosion control and surface stability (Boreal Ecology, 1989b). Revegetation trial areas can also be utilized to evaluate recovery of native or other species in relation to fertilizer and seeding treatments.

4.5 MONITORING AND REPORTING

Interprovincial Pipe Line (NW) Limited is required to monitor and report on the effects of the pipeline construction and operation on the environment, the condition of the right-of-way and the condition of the pipeline. Specific monitoring requirements were included in the Certificate of Public Convenience and Necessity No. OC-35 (National Energy Board) and water licences issued for the Great Bear and Mackenzie River pipeline crossings (Northwest Territories Water Board).

Figure 4-8. Winter maintenance and remedial work along the Norman Wells pipeline.

a) Large tracked vehicles are used to resupply propane to remote valve sites. Helicopters are generally used for regular line patrols, special monitoring, and most summer work along the right-of-way. (km 819, March 1987).

b) Replacing wood chips removed from a "hot spot" on a wood chip insulated slope (km 272, March 1989) and an example of IPL thermal instrumentation.

Figure 4-9. Example of equipment used for summer remedial work on the Norman Wells pipeline. Light tracked vehicle called a Bobcat being used to blade organic material back into the ditch. (September 1985).

To meet commitments under OC-35, IPL prepared a report called "Post Construction Monitoring Programs for the Norman Wells to Zama Pipeline" which includes a schedule for monitoring (Table 4-8). It was approved by the National Energy Board in October 1984. One of the requirements is to file an annual report each November 30. The report contains information on operational and maintenance activities, condition of the pipeline (thaw settlement, frost heave, exposed pipe), terrain monitoring (e.g. ditchline subsidence, surface erosion, slope stability, wood chip performance), revegetation monitoring, aquatic monitoring and others (raptor, wildlife). It usually contains a schedule of restoration/maintenance work proposed for the upcoming winter and data from instrumentation such as temperature data from slopes, the pipe and the ditch area. IPL has completed six annual reports (1983 to 1988) on the Norman Wells Pipeline Project. Examples of monitoring reports prepared by IPL are listed in Table 4-9.

In 1987 and 1988, IPL started development and testing of a special monitoring pig to improve the evaluation of pipe condition and geometry (Adams et al., 1989a and 1989b; Pare et al., 1989). Visual and external surveys of the pipe were not considered adequate for detection of pipe changes and differential pipe settlement. Testing the special monitoring pig in the Norman Wells to Zama pipeline began in March 1989.

Table 4-8. Schedule of IPL terrain related post-construction monitoring programs on the Norman Wells Pipeline.

Program	Initiate	Terminate	Frequency
Standard Operational Monitoring			
- Aerial Surveillance	1984	Lifetime[1]	Weekly
- Ground Inspection	1984	Lifetime	Annual
Geotechnical Monitoring			
- Thaw Settlement	1984	Lifetime[2]	Annual
- Frost Heave	1984	Lifetime[2]	Quarterly
- Slope Performance	1984	Lifetime[2]	Eight/Yr
Aquatic Monitoring			
- Mackenzie and Great Bear	1985	Lifetime	Annual
- Others	1984	1986	Annual
Revegetation Monitoring			
- Aerial Survey	1984	1987	Annual
- Baseline Data Collection	1984	1985	Annual
- Permanent Sample Transects	1984	1987	Annual
- Revegetation Trial Sites	1984	1987	Annual
Aerial Photography and Ground Truthing	1986	1988	Biennual

1. Lifetime refers to the operational life of the pipeline.

2. Monitoring may be discontinued if history of readings indicates an equilibrium situation.

Table 4-9. Examples of recent monitoring reports prepared by IPL on the Norman Wells to Zama Pipeline.

1985

Norman Wells Pipeline Project - 1985 Report on Monitoring of Construction and Operation.

Water Quality Monitoring in Relation to 1985 Construction and Operation.

Aquatic Monitoring Survey, Norman Wells to Zama Pipeline, July, 1985.

Wildlife Monitoring Studies Along the Norman Wells - Zama Oil Pipeline January - March 1985.

Revegetation Monitoring of the Interprovincial Pipe Line (NW) Ltd. Norman Wells to Zama Pipeline.

Norman Wells to Zama Pipeline - July, 1985 Revegetation Program.

Interprovincial Pipe Line (NW) Ltd. Norman Wells to Zama Pipeline Revegetation Activities, March - April 1984 and February - March 1985.

1986

Interprovincial Pipe Line (NW) Ltd. 1986. Norman Wells Pipeline Project - 1986 report on monitoring of construction and operation.

_____. 1986. Norman Wells pipeline project revegetation activities January - March 1986 and July 1986.

Fernet, D.A. 1986. Aquatic monitoring survey Norman Wells to Zama pipeline July 1986.

Hardy BBT Limited. 1986. Interpretation of aerial photographs Norman Wells to Zama pipeline.

1987

Interprovincial Pipe Line (NW) Ltd. 1987. Norman Wells Pipeline Project - 1987 report on monitoring of construction and operation.

Canuck GIE Engineering Ltd. 1987. Norman Wells to Zama Pipeline, 1986/87 winter restoration program, revegetation report.

Hardy BBT Limited. 1988. 1987 revegetation monitoring of the Interprovincial Pipe Line (NW) Ltd. Norman Wells to Zama Pipeline.

Hardy BBT Limited. 1988. Norman Wells Pipeline, organic terrain revegetation trials, 1987 report.

Fernet, D.A. 1987. Aquatic monitoring studies of the Norman Wells to Zama oil pipeline, 1984-1987.

Eccles, T.R. and J.A. Duncan. 1987. Wildlife monitoring studies along the Norman Wells to Zama oil pipeline, November 1984 - May 1987.

5. COMPARISONS WITH OTHER PIPELINES

The only major operational oil pipeline in permafrost areas in North America at the time of Norman Wells Pipeline construction was the Trans-Alaska Pipeline System (TAPS) carrying oil from the north coast (Prudhoe Bay) to the south coast (Valdez) of Alaska. This is a large diameter (122 cm, 48-inch) pipeline carrying large volumes of hot oil. Important lessons have been, and continue to be, learned from this pipeline project.

There are also two operational northern gas pipelines:

1) the Pointed Mountain pipeline from Fort Liard, N.W.T., to Beaver River, British Columbia, (51 cm, 20-inch) and
2) the TAPS fuel gas line from Prudhoe Bay to Pump Station 4 along the Trans-Alaska oil pipeline (20 and 25 cm, 8 and 10 inch).

The former is in the southern part of the discontinuous permafrost zone; the latter is in the continuous permafrost zone.

In addition there is considerable experience with oil and gas pipelines in permafrost areas of the Soviet Union although information has been relatively limited (Williams, 1986). Permafrost and other problems have caused ecological and safety concerns: environmental protection has now become a higher priority for northern pipelines in the Soviet Union (Melnikov, 1988).

5.1 CANOL PIPELINE (NORMAN WELLS TO WHITEHORSE)

There was one previous attempt to transport Norman Wells oil overland by pipeline from Norman Wells to Whitehorse during World War II (1944 - 1945). This pipeline was part of the Canol Project undertaken by the United States Army. A small diameter pipe (10 and 15 cm; 4 and 6-inch) was laid on the ground surface along a service road (Finnie, 1945; Barry, 1985; Williams, 1986). The pipeline, which experienced several leaks and breaks during its eleven months of operation, was abandoned in April 1945 (Barry, 1985).

5.2 POINTED MOUNTAIN NATURAL GAS PIPELINE

The next hydrocarbon pipeline in the Northwest Territories was Westcoast Transmission Company Limited's Pointed Mountain natural gas pipeline constructed in winter 1971-72 from Amoco's

Pointed Mountain Gas Field near Fort Liard, N.W.T., through the southeast corner of Yukon to connect with the Westcoast Beaver River pipeline in British Columbia (Table 5-1). In 1972 this 51 km (34 mi) long pipeline became the most northern operational gas pipeline in North America (Yamauchi, 1977). It was also the first pipeline built under the rules of the new Territorial Land Use Regulations.

Table 5-1. **Selected comparisons among two small northern gas pipelines and the Norman Wells oil pipeline.**

Pipeline	"Pointed Mountain Gas Pipeline"	TAPS "fuel gas line"[1]	Norman Wells Pipeline
Location	Fort Liard, NWT to Beaver River, B.C.	Prudhoe Bay to Pump Station 4 Alaska	Norman Wells, NWT to Zama, Alberta
Length	51 km (34 mi)	230 km (150 mi)	869 km (539 mi)
Diameter	51 cm (20-in)	20, 25 cm (8, 10 in)	32 cm (12.7 in)
Construction Mode	buried	buried	buried
Construction ROW Width	24 m (80 ft)	**	30 m (98 ft)
Opening	1972	1977	1985
Environment	forest region (boreal)	tundra (arctic)	forest region (subarctic, boreal)
Permafrost Zones	discontinuous (sporadic)	continuous	discontinuous

1. TAPS (Trans-Alaska Pipeline System).
ROW (Right-of-way)

**. Adjacent to all weather haul road or to oil pipeline work pad.

Shallow permafrost was encountered intermittently in northern sections of the route (< 5% of length; Heginbottom, 1974). No information was obtained on the thermal effects of construction or operation of the pipeline on the shallow permafrost encountered (Heginbottom, 1974).

Backhoes and bulldozers were used to trench most of the pipeline (minimum pipe depth of about 75 cm). In the shallow permafrost areas the ditch was excavated to greater depths (1.5-2 m) to remove icy soils wherever possible (Owen and Van Eyk, 1975; Yamauchi, 1977).

Localized areas of subsidence have occurred. Some areas of "sunken ditchline", developed into watercourses on sloping ground, resulting in gullying and erosion (Owen and Van Eyk, 1975; Yamauchi, 1977). Remedial work has been undertaken at several slopes and at the Kotaneelee River crossing where the pipe was exposed in the crossing. The temperature of gas entering the pipeline is about 20°C with a current (1988) throughput of about 20 million cubic feet per day (Amoco, personal communication).

5.3 TRANS-ALASKA PIPELINE SYSTEM

At the same time that proposals for large gas pipelines were being reviewed in Canada (Berger, 1977; Lysyk et al., 1977), the large diameter TAPS oil pipeline was being constructed in Alaska to transport oil from Prudhoe Bay south to Valdez. In addition a small diameter natural gas pipeline was constructed at Prudhoe Bay to TAPS Pump Stations 1, 2, 3, and 4 to provide fuel for the turbines at those Pump Stations (Table 5-1).

The buried fuel gas pipeline, initially expected to be installed in one winter (1975-1976) using a constructed snowpad, required two winters of construction plus completion of backfilling in summer (Brown and Berg, 1980). Summer backfilling, clean-up, and remedial work was feasible since the fuel gas line was generally located within five meters of an all-weather haul road or the gravel work pad for the oil pipeline. Various types of equipment (e.g. wheel trencher, Roc-Saw) and construction procedures (snow handling, organic layer removal, trenching methods, spoil placement, special backfilling and polystyrene insulation, and erosion controls) were tested and refined (Brown and Berg, 1980). The fuel gas pipeline operates near ground temperatures . Input gas temperatures have been variable depending on the year of operation and the season of the year, ranging from several degrees below 0°C to several degrees above 0°C. To reduce the summer gas temperatures and subsequent soil thawing, a chiller was installed at Pump Station 1 in 1984 (P. McDevitt, personal communication).

The Trans-Alaska oil pipeline and the Norman Wells oil pipeline represent contrasting scales, histories, and approaches. Some of these differences related to construction and to operations are given in Tables 5-2 and 5-3. The TAPS oil pipeline is about four times larger in diameter than the Norman Wells line with an initial proposed design capacity of 2 billion barrels per day compared to 25,000-30,000 barrels per day for the Norman Wells Pipeline.

Prior to laying of pipe in Alaska, permanent roads were constructed by the Alyeska Pipeline Service Company adjacent to about half of the pipeline's length. A 90 km section of road was built from existing roads to the Yukon River in 1969-1970 and a second 577 km section was built in 1974 from the Yukon River to Prudhoe Bay (right-of-way 67 m wide). The latter "Haul Road", called the Dalton Highway, was turned over to the State of Alaska in 1978. These roads provide winter and summer access to the pipeline area.

In contrast, permanent road access to the Norman Wells pipeline during construction, and at the current time (to 1989), is limited to the following: a few km in Norman Wells, access from a few barge landing sites along the Mackenzie River, a few km from Wrigley to the Wrigley Pump Station and one Mackenzie Highway-pipeline crossing at km 585 where the Mackenzie Pump station is located. Permanent access may increase between Fort Simpson and Wrigley in the next few years (1991 or later) when a new section of the Mackenzie Highway opens. Thus, unlike TAPS, most Norman Wells pipeline remedial work is scheduled in winter, when access is available to and on the right-of-way using temporary snow roads.

Climate, soil and seismic conditions along the TAPS route were considered unusual and required special designs (Liguori et al., 1983; Lusher 1977). Because of permafrost and the anticipated effects of hot oil in the pipeline, the pipeline was elevated wherever it was anticipated that the soil would become unstable when thawed. The pipe was elevated for over half of its length (approximately 422 mi; Liguori et al., 1983; Lusher, 1977). Where the pipeline had to be buried in thaw-sensitive soil (animal and highway crossings), a special refrigerated design was used (about 4 mi in total). Thermal designs for the vertical support members (VSM's) for the elevated sections of pipe varied depending on conditions such as permafrost temperatures and amounts of ground ice.

The owners of TAPS signed an Agreement and Grant of Right-of-Way and a right-of-way lease with the federal Secretary of the Interior and the State of Alaska respectively. The

Table 5-2. Construction comparisons of the Norman Wells pipeline and the Trans-Alaska oil pipeline.

	Trans-Alaska Pipeline	Norman Wells Pipeline
Origin	Prudhoe Bay, Alaska	Norman Wells, Northwest Territories
Terminus	Valdez, Alaska	Zama, Alberta
Length	1300 km (800 mi)	869 km (539 mi)
Diameter	122 cm (48 in)	32 cm (12.7 in)
Construction Mode	elevated and buried	buried
Construction ROW Width	46-61 m (150-200 ft)	30 m (98 ft)
Construction Timing (trenching)	1975-77 winter and summer	1983-1985 winter (overland)
Opening	August 1, 1977	April 17, 1985
Environment	tundra, forest (arctic, subarctic, boreal)	forest region (subarctic, boreal[3])
Permafrost Zone	continuous discontinuous	discontinuous
Total Surface Disturbance Caused by Construction	12,712 ha[1] (31,400 acres)	2,597 ha[2] (6,415 acres)
Approx. cost of Construction	$7-8 billion	$300-400 million

1. Figure from "Environmental surveillance during construction of the Trans-Alaska Pipeline System" Sept. 1977.
2. Figure from Land Resources INAC. Area as calculated in September 1985. Excludes areas associated with remedial work in the winter of 1985-86 to present.
3. Includes 3 ecoclimatic regions: Low subarctic, High boreal and Mid-boreal (Ecoregions Working Group, 1989).

Table 5-3. Operational comparisons of the Norman Wells pipeline and the Trans-Alaska oil pipeline.

	Trans-Alaska Pipeline	Norman Wells Pipeline
"Thermal Design"	"hot"	"ambient" (near ground temperature)
Input oil Temperature	approx. 60°C (145°F)[1.]	approx. -2°C (29°F)
Volume	approx. 1.6 - 1.8 million b/d (1986)	approx. 20,000 to 25,000 b/d (1986)[2.]
Pump Stations	5-12	3
Control Center	Valdez	Norman Wells
Communications	microwave system satellite back-up	microwave system
Primary Ground Access	gravel workpad Haul Road (all-weather)	temporary winter access limited all-weather access

1. Operating oil temperatures vary: from 38°C to 63°C (Thomas and Ferrell, 1983); from 49°C to 62°C (Ferrell and Thomas, 1988).
2. Norman Wells Pipeline throughput was approximately 30,000 b/d in 1988.

pipeline system construction officially began in early 1974, with actual pipeline construction (ditching and pipe laying) beginning in early 1975. Pipeline construction was completed in May 1977.

First oil entered the line on June 20, 1977, and the opening of the line occurred on August 1, 1977. Oil flow approached the nominal design capacity of 1.2 million barrels a day in 1978. Ten years later, the Trans-Alaska pipeline is transporting about 1.5 million barrels per day (238,000 $m^3/_d$) or about 24 percent of the United States' domestic oil production (Ferrell and Thomas, 1988).

In addition to the haul roads, almost all of the oil pipeline was constructed from a 15 m (50 ft) wide gravel overlay workpad which was considered essential for construction, operation and maintenance of the oil pipeline and the fuel gas line (Metz et al., 1982; Metz, 1984). Some short experimental snow roads and ice pads were also used.

The pipeline was designed to perform within acceptable settlement limits for 25 years based on probable depths of thaw below the pipeline as a function of time, temperature of the oil and thermal conductivity of the ground (maximum design subsidence 0.91 m; Johnson, 1981). Two ruptures ocurred in buried sections of the Trans-Alaska pipeline in June 1979 (23 months after opening):

1) at Milepost 166 on the north side of Atigan Pass in the Brooks Range and
2) at Milepost 734 (Johnson, 1983; Stanley and Cronin, 1983; Thomas and Ferrell, 1983).

At Atigan Pass, the failure was attributed to excessive settlement (up to 1.22 m) due to melting of ice in fractured bedrock. Bedrock here contained ice masses up to 3.3 m thick (Stanley and Cronin, 1983). At Milepost 734, 1.7 m of settlement occurred in about a 90 m zone where unstable ice-rich permafrost had not been recorded during trenching and where normal pipe burial for thawed soil had been used (Johnson, 1983; Thomas and Ferrell, 1983). The bend in the pipe caused it to rupture. "Inplace" stabilization procedures were used at both locations.

In reviews of both pipe failures, it was found that surface changes indicating thaw settlement had been present before the pipe failed. By monitoring and noting these changes in future, areas of substantial settlement could be identified for examination, and remedial work could be undertaken to prevent pipe rupture. Since 1979, the Alyeska Pipeline Service Company has placed more emphasis on terrain monitoring, (visual observations, monitoring rods on pipe, boreholes, thermistor cables) especially in settlement prone areas (Johnson, 1983 and 1986; Thomas and Ferrell, 1983). The program resulted in locating and repairing areas where the pipe was approaching buckling curvature. By 1983, it was considered that the thaw bulb and thaw penetration had slowed sufficiently for a small (less than 15 mm/yr) settlement rate (Thomas and Ferrell, 1983).

In 1984 an unexpected area of settlement of several meters (a maximum of 4.6 m) was detected at the Dietrich River crossing (Simmons and Ferrell, 1986). A Corrosion and Deformation (C/D) pig traversing the TAPS pipe in June 1984 detected a "wrinkle", or wall anomaly, in the pipe shape at the Deitrich River which was subsequently investigated. Massive ice was found below the river channel at depths of 14-15 m. Analyses indicated the ice lens was about 5.5 m thick at the start of pipeline operation and that the remaining 0.9 m would melt in about three years producing an average rate of settlement of about 30 cm per year (Simmons and Ferrell, 1986). To eliminate risk of an oil spill into a sensitive northern river, two temporary bypass pipelines were built and a permanent reroute was constructed in winter 1985. The reroute was approximately 1.2 km long and cost about $27 million (Simmons and Ferrell, 1986).

Simmons and Ferrell (1986) emphasized that a monitoring system was essential, especially in river and floodplain areas where evidence of surface disturbances may be obliterated. They noted that surface evidence is not a particularly reliable indicator of pipe settlement. They recommended that the best possible materials and quality control should be used during construction in inaccessible areas such as in floodplains and river crossings. Simmons and Ferrell also noted that there was a need to improve pipe curvature data collection and analyses to accurately predict pipe integrity.

Monitoring, detection of potential problems, and repair to the TAPS pipeline is on-going (Johnson, 1986). A summary table of thaw settlement problems and solutions for the 1980-1988 period is given in Ferrell and Thomas (1988). They advised developing numerous potential remedial solutions (such as overburden relief, underpinning, relevelling, grouting, ground freezing, remoding and rerouting) which can be modified and used as required. One of the successful relevelling techniques uses pressurized air bags. An important lesson learned on TAPS is that some occurrences of ice-rich permafrost were missed despite intensive subsurface investigations (boreholes, detailed ditch log) .

6. SUMMARY

The 869 km (539 mi) long, 324 mm (12.7 in) diameter Norman Wells, N.W.T. to Zama, Alberta, pipeline, owned and operated by Interprovincial Pipe Line (NW) Ltd., is the first completely buried oil pipeline in discontinuous permafrost in northern Canada. Review of the pipeline project, which is entirely on crown lands within the N.W.T. and Alberta, was initiated in 1980. The main anticipated terrain disturbances focused on thaw settlement, slope stability, drainage disruption and the potential for subsequent erosion. Significant concerns identified by the Environmental Assessment Panel included: 1) pipeline integrity in permafrost, 2) short and long term right-of-way stability, 3) karst terrain, and 4) water crossings. Detailed designs, approaches and mitigative measures were developed as a result of project planning in 1980 to 1983.

Three special agreements were signed between INAC and IPL. One, an "Environmental Agreement", established principles of environmental protection, co-operative monitoring and evaluation of environmental management. INAC and EMR initiated preliminary plans for a Permafrost and Terrain Research and Monitoring Program with the goal, as identified in the Agreement, to improve impact evaluation and mitigation on the Norman Wells pipeline and future projects. The initial program was expanded to include National Research Council (evaluation of wood chip insulation performance) and Agriculture Canada (evaluation of near surface soil and air temperatures).

REGIONAL ENVIRONMENTAL FRAMEWORK

In general, the Norman Wells Pipeline corridor experiences a cold, continental climate with a wide annual temperature range and relatively low levels of precipitation. The long winters are cold, with mean monthly temperatures below -20°C , while the summers have three months with mean temperatures above 10°C. There is a general north-south increase in temperature along the pipeline route; mean annual temperature is -6.4°C at Norman Wells, -4.2°C at Fort Simpson, and -2.0° C at High Level (1951-1980 climate normals). From an ecoclimatic region perspective the pipeline falls within the low subarctic zone in the north (Norman Wells to Fort Norman) and the high and mid-boreal zones to the south.

Rainfall within the pipeline corridor occurs between April and November; however, peak rainfall occurs during the period June to September, often in the form of intense rainstorms. In most cases, the area affected by such storms is smaller than the spacing between meteorological stations. Snowfall generally begins in

late-September and the highest snowfall occurs between October and December.

The Norman Wells pipeline traverses three major physiographic regions, the Mackenzie Plain, Great Slave Plain, and the Alberta Plateau. The topography along most of the pipeline route is relatively subdued; the highest elevation on the line occurs on the Alberta Plateau. In the north, steep slopes are encountered at crossing points of valleys deeply incised by streams flowing into the Mackenzie River. Between Norman Wells and Willowlake River, lacustrine and moraine (till) terrain types predominate. From Willowlake River south to the Mackenzie River crossing the moraine component becomes dominant. South of the Mackenzie River crossing, there is a marked increase in the proportion of organic terrain.

The Norman Wells Pipeline almost completely transects the discontinuous permafrost zone. Permafrost is widespread in the northern portion of the pipeline route, being generally less than 50 m but not more than 80 m thick. Mean annual ground surface temperatures are generally negative in this region and range from -1 to -3°C. Along the southern portion of the pipeline route, positive ground surface temperatures are more frequently observed; permafrost is generally scattered, at temperatures close to the melting point (between -1 and 0°C) and less than 20 m thick. Permafrost soils are often ice-rich containing excess ground ice in a variety of forms, including lenses, veins, and irregular ice masses. Based on IPL geophysical surveys frozen ground underlies about 75% of the terrain in the northern half, and 25% of the terrain in the southern half of the route. In general, as permafrost becomes more sporadic from north to south, the frequency of transitions from frozen to unfrozen ground tends to increase.

Many global change scenarios predict a pronounced warming of northern regions over the next several decades accompanied by considerable increases in precipitation. Analysis of existing air temperature data from meteorological stations in the Mackenzie Valley shows significant increases of about 1 K in the past 50 years. Some of the possible changes in permafrost due to climate change include 1) increased depth of seasonal thaw, 2) long term degradation of permafrost, 3) increases in mass movements on slopes, and 4) changes in the mechanical behaviour of frozen ground.

DESIGN AND MITIGATIVE APPROACHES

Numerous approaches were applied by IPL to ensure integrity of the pipeline, minimize the effects of the pipeline on the environment and minimize the effects of the environment on the pipeline. IPL's design concepts for limiting the pipe's energy input to thaw-sensitive soils and increasing pipe strength represent a significant change from previous pipelining practice.

Other approaches to minimize environmental impacts include minimizing the length of the pipe in thaw-sensitive terrain, locating the pipe in previously cleared terrain, retarding or preventing thaw of sensitive slopes and frequent monitoring and rapid response to unstable conditions such as overland or streambank erosion. The Company also prepared, and implements, an Environmental Protection Plan, a new requirement for Canadian pipeline projects.

CONSTRUCTION AND OPERATION

Main pipeline construction was completed during the winters of 1983-1984 and 1984-1985. Approximately 165 slopes required geotechnical evaluation and design. Three main slope mitigation approaches were used: 1) "prevent thaw", 2) "retard thaw" and 3) "cut back". Site specific designs were developed for 57 water crossings. Although IPL's easement was 30 m in width, clearing was usually held to 25 m or less. The extent of grading or snow pack cover used on the right-of-way during construction varied and was determined by the Company. Air rather than liquid was used to pressure test the pipe.

The pipeline became operational in April 1985 with a design capacity of approximately 4800 m^3/day (30,000 b/d) and an expected life of approximately 25-30 years. The pipeline system consists of three pump stations with a control centre based at Norman Wells. The pump stations and all remote control valves are linked by microwave. There are 20 remotely operated valves and 28 manual ones. Oil movement from Norman Wells has increased from an average of 21,700 b/d in the first year of operation to 26,100 b/d in the third year of pipeline operation. IPL monitors the oil temperature as it enters the Norman Wells Pump Station; if there are problems in delivery of chilled oil, IPL may shut down the pipeline.

The total federally administered land area in the N.W.T. used during construction of the project was approximately 2600 hectares (ha) of which 1500 ha are now under lease or easement. Approximately 462 ha were used to supply timber for wood chips to insulate 55 slopes. An additional 78 ha of land have been used, or re-used, under land use permits through October 1988. A total of approximately 630,000 yd^3 (482,000 m^3) of granular and borrow materials have been used during construction (61%, 1983-1985) and operations (39%, 1986-1988).

Post-construction permafrost and terrain effects are discussed and evaluated in Volume II of this report. Volume II presents observations and analyses on the pipe and ground thermal regimes, overall terrain performance, and the thermal performance of wood chip insulation of thaw-sensitive slopes, as well as conclusions and recommendations based on the first three years of pipeline operation.

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APPENDIX A

GLOSSARIES

Table A-1: Permafrost related terms

Table A-2: Pipeline related terms

Table A-1. Glossary of permafrost related terms.

(from "Glossary of Permafrost and Ground-Ice Terms", National Research of Canada, Technical Memorandum 142, 1988, 156 pp.)

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active layer - The top layer of ground subject to annual thawing and freezing in areas underlain by permafrost.

depth of thaw - The minimum distance between the ground surface and frozen ground at any time during the thawing season.

freezing (of ground) - The changing of phase from water to ice in soil or rock.

freezing front - The advancing boundary between frozen (or partially frozen) ground and unfrozen ground.

freezing-point depression - The number of degrees by which the freezing point of an earth material is depressed below 0°C.

freezing pressure - The positive (heaving) pressure developed at ice-water interfaces in a soil as it freezes.

frost, seasonal - The occurence of ground temperatures below 0°C for only part of the year.

frost bulb - A more or less symmetrical zone of frozen ground formed around a buried chilled pipeline or beneath or around a structure maintained at temperatures below 0°C.

frost heave - The upward or outward movement of the ground surface (or objects on, or in the ground) caused by the formation of ice in the soil.

frost-stable ground - Ground (soil or rock) in which little or no segregated ice will form (causing frost heave) under the required conditions of moisture supply and temperature.

frost-susceptible - Ground (soil or rock) in which segregated ice will form (causing frost heave) under the required conditions of moisture supply and temperature.

frozen ground - Soil or rock in which part or all of the pore water consists of ice.

ground thermal regime - A general term encompassing the temperature distribution and heat flows in the ground and their time - dependence.

ice, excess - The volume of ice in the ground which exceeds the total pore volume that the ground would have under natural unfrozen conditions.

ice, ground - A general term referring to all types of ice formed in freezing and frozen ground. (ice lens, ice wedges, pingo ice).

ice, segregated - Ice formed by the migration of pore water to the frozen fringe where it forms into discrete layers.

ice content - The amount of ice contained in frozen or partially frozen soil or rock.

ice lens - A dominantly horizontal, lens-shaped body of ice of any dimension.

latent heat - The volumetric latent heat of fusion is the amount of heat required to melt the ice (or freeze the water) in a unit volume of soil.

palsa - A peaty permafrost mound possessing a core of alternating layers of segregated ice and peat or mineral soil material.

Table A-1. (continued)

peatland - Peat-covered terrain

peat plateau - A generally flat-topped expanse of peat, elevated above the general surface of a peatland, and containing segregated ice that may or may not extend downward into the underlying mineral soil.

permafrost - Ground (soil or rock) that remains at or below 0°C for at least two years.

permafrost, continuous - Permafrost occurring everywhere beneath the exposed land surface throughout a geographic region with the exception of widely scattered sites, such as newly deposited unconsolidated sediments, where the climate has just begun to influence the ground thermal regime causing the formation of continuous permafrost.

permafrost, discontinuous - Permafrost occurring in some areas beneath the exposed land surface throughout a geographic region where other areas are free of permafrost. Near its northern boundary, discontinuous permafrost is widespread, whereas near its southern boundary it occurs in isolated patches or islands and is commonly referred to as "sporadic".

permafrost, equilibrium - Permafrost that is in thermal equilibrium with the existing mean annual ground-surface or sea-bottom temperature and with the geothermal heat flux.

permafrost, ice-rich - Permafrost containing excess ice.

permafrost, thaw-sensitive - Perennially frozen ground which, upon thawing, will experience significant thaw settlement and suffer loss of strength to a value significantly lower than that for similar material in an unfrozen condition. Ice-rich permafrost is thaw-sensitive.

permafrost, thaw-stable - Perennially frozen ground which upon thawing, will not experience either significant thaw settlement or loss of strength.

permafrost aggradation - A naturally or artificially caused increase in the thickness and/or a real extent of permafrost.

residual thaw layer - A layer of thawed ground between the seasonally frozen ground and the permafrost table (the upper boundary of permafrost).

solifluction - Slow downslope flow of saturated unfrozen earth materials.

talik - A layer or body of unfrozen ground in a permafrost area.

thaw basin - A depression of the permafrost table created by naturally induced thawing (e.g. beneath lakes or rivers that do not freeze to the bottom in winter).

thaw bulb - A more or less symmetrical area of thaw in permafrost surrounding a man-made structure.

Table A-1. (continued)

thaw consolidation - Time-dependent compression resulting from thawing of frozen ground and subsequent drainage of pore water.
thaw settlement - Compression of the ground due to thaw consolidation.
thaw slumping - A slope failure mechanism characterized by the melting of ground ice, and downslope sliding and flowing of the resulting debris.
thawing index - The cumulative number of degree-days above 0°C for a given time period.
thermal erosion - The erosion of ice-rich permafrost by the combined thermal and mechanical action of moving water.
thermokarst - The process by which characteristic land forms result from the thawing of ice-rich permafrost.
thermokarst terrain - the irregular topography resulting from the melting of excess ground ice and subsequent thaw settlement.
thermosyphon - A passive heat transfer device installed to remove heat from the ground.
water, pore - Water occurring in the pores of soils and rocks.
water content, total - The total amount of water (unfrozen water & ice) contained in soil or rock.
zero curtain - The period of time during which a nearly constant temperature, very close to the freezing point, exists during annual freezing (and occasionally during thawing) of the active layer.

Table A-2. Glossary of some pipeline related terms.

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backfill - excavated material from the ditch that was placed back over pipeline.
  native, local - backfill replaced from original location
  select - other material usually non ice-rich and more stable, from quarries
buckling - change in pipe cross section due to longitudinal bending, which may be promoted by differential soil movement along the pipe axis
chainage, plan, - preliminary survey distances before construction (Norman Wells - kp 0)
  "as built" final survey distances after construction including any alignment changes (final length 869.48 km)
curvature - aspect of pipe's displaced profile with respect to its longitudinal profile (change in slope)
pig - device sent down the inside of a pipeline to perform various functions as in a scraper pig to clean the inside of the pipe
  "super pig" a pig instrumented with tools to aid in internal monitoring of the pipeline conditions
  "caliper pig" measures ovality of the cross-section of the pipe with mechanical calipers to detect circumferential wrinkles (used on TAPS to detect wrinkles)
push outs - areas adjacent to the R.O.W., used for disposal of unstable excavated ditch spoil
roach - high mound of unconsolidated spoil or backfill placed over the pipe and ditch area (during winter construction may include ice and snow)
sag bend - deeper buried portion of pipe below a water crossing or channel
sag points - points at which the pipeline is brought up from deeper burial below a water crossing
shoo fly - travel detour around steep slopes or water crossings
spoil - material excavated from the pipeline ditch
stress - generated from operating and bending conditions
throughput - volume of oil flow per unit time
weights - structures placed on the pipe to prevent buoyancy (e.g. saddle weights)
wrinkles - may result from bending of the pipe, on the compression side of the pipe

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APPENDIX B

MAIN CONCLUSION AND ENVIRONMENTAL REASONS FOR THE MAIN CONCLUSION, AS STATED IN THE REPORT OF THE ENVIRONMENTAL ASSESSMENT PANEL: "NORMAN WELLS OILFIELD DEVELOPMENT AND PIPELINE PROJECT" (DUFFY, 1981)

THE MAIN CONCLUSION AND ENVIRONMENTAL REASONS FOR THE MAIN CONCLUSION, AS STATED IN THE REPORT OF THE ENVIRONMENTAL ASSESSMENT PANEL: "NORMAN WELLS OILFIELD DEVELOPMENT AND PIPELINE PROJECT", JANUARY 1981.

Main conclusion

Before the Norman Wells Oilfield Expansion and Pipeline Project can be built within acceptable limits of environmental and socio-economic impact, the following important deficiencies in the Proponents' planning and in the preparedness of governments need to be rectified. The Panel has concluded this work could be done in time to start work on the project in 1982. The reasons for this overall conclusion are given below and specific recommendations on them are given in the following section of this chapter.

Environmental Reasons

1. Esso should undertake a model study of local scour on the artificial islands at Norman Wells to determine the potential for scour, the level of monitoring required, and the development of remedial or contingency measures.

2. Esso should study the alternative to the filter cloth design on the artificial islands to ensure that erosion of the artificial islands is minimized.

3. Esso should undertake an accelerated research and technology development program on oilspill countermeasures and for equipment to deal with oilspills into or under ice-covered or ice-infested river water.

4. Esso and IPL should develop a detailed oilspill and toxic and hazardous materials contingency plan which should be in place prior to the start of drilling from artificial islands and construction of the pipeline. This plan should include provision for a more accurate oilleak detection system for the oilfield project. The contingency plans should cover the construction and operational phases of the oilfield and pipeline project. The plans should be developed, tested, evaluated and approved by the responsible government agency prior to the start of construction.

5. IPL should carry out and publish the results of a detailed thermal analysis of the pipeline in different terrain types in different seasons. The objective of the study is to understand the potential for thaw settlement and frost heave, ponding of water, and erosion of the pipeline ditch as well as ultimate repair and rehabilitation requirements.

APPENDIX C

ENVIRONMENTAL AND ENGINEERING RECOMMENDATIONS

for the Norman Wells Pipeline Project

made by the

Federal Environmental Assessment and Review Panel

(Duffy, 1981)

ENVIRONMENTAL AND ENGINEERING RECOMMENDATIONS (DUFFY, 1981)

Pipeline Alternatives

1. It is recommended that IPL investigate minor alternative routings to keep the pipeline further east from the settlements of Fort Norman and Wrigley.

Geotechnical Concerns, Pipeline Integrity and Permafrost

2. It is recommended that pipeline summer construction be permitted only in areas where it can be clearly demonstrated that there would be no greater impact than winter construction in the same area.

3. It is further recommended that, before the project is authorized, IPL undertake and publish a more detailed thermal analysis of the pipeline to predict more accurately the behavior of the pipe in a variety of terrain and temperature regimes. The analysis should cover the possibilty of climatic change over the life of the project.

4. It is recommended that detailed and environmentally acceptable plans for the maintenance of the right-of-way and for the repair of pipeline failures be prepared prior to commissioning of the pipeline.

5. It is recommended that terms and conditions for the pipeline project spell out requirements for a revegetation and erosion control program using species, techniques and schedules shown to be adequate for the task.

6. It is recommended that in developing oilspill prevention and contigency plans, IPL make special provisions for the karst terrain near Bear Rock.

7. It is recommended that IPL design, plan, and construct the pipeline so as to minimize the need for extensive maintenance or unscheduled repair activities.

Water Crossings

8. It is recommended that river crossings be located so as to minimize overall environmental disruption.

9. It is recommended that the construction plans and schedules for intermediate sized crossings be re-evaluated by IPL in cooperation with the Department of Fisheries and Oceans to ensure that impacts on fish and other aquatic organisms are minimized.

Island Construction

10. It is recommended that Esso carry out a model study to fully evaluate local scour at the artificial islands in order to be certain of the structural safety of the pipelines and integrity of the islands. The study should include monitoring and remedial repair procedures. The results should be reviewed by government before construction is authorized.

11. It is further recommended that studies on alternatives to filter cloth protection be carried out to find a material that will ensure that no significant erosion of the islands will occur. Results should be reviewed by government before construction of the islands is authorized.

Fisheries and Wildlife

12. It is recommended that the Proponents consult with the department of Fisheries and Oceans to address any outstanding fisheries concerns and demonstrate in their construction timing that they have used available information and addressed the concerns.

13. It is recommended that further site specific studies be undertaken to determine final alignment for river crossings to prevent or minimize impacts on fish and the aquatic environment.

14. It is recommended that IPL undertake baseline studies on hunted and trapped species to provide information aimed at both the assessment of the impact of the pipeline construction and operation on wildlife, and the development of mitigation measures.

15. It is recommended that construction and drilling activity on the islands stop during the peak spring waterfowl migration period that normally lasts one to two weeks, and that helicopter access to the islands be restricted to only essential needs.

16. It is recommended that Esso develop a plan specifying the necessary equipment and procedures to keep large populations of waterfowl away from an oilspill site.

Forests and Wildfires

17. It is recommended that government and IPL fire contol responsibilities be clarified prior to commencement of construction and operation of the pipeline. It is further recommended that the government fire control program be augmented to provide protection to the pipeline and, at the same time, that there be no decrease in protection services to other sectors, such as highways, settlements and traplines.

18. It is recommended that slash from the right-of-way clearing operation be piled and burned on the right-of-way during the winter.

Oilspills Prevention and Countermeasures

19. It is recommended that Esso undertake an accelerated research and technology development program on equipment and procedures to deal with oilspills into or under ice-covered and ice-infested river waters. This program should be in place before expanded production begins at Norman Wells.

20. It is recommended that Esso investigate, design and install a more accurate oil-leak detection system at Norman Wells, one that would be consistent with the detection levels of the IPL pipeline to Zama.

21. It is recommended that Esso and IPL develop, test, and evaluate contigency plans for the construction and operation of both the oilfield expansion and pipeline projects and that these plans be reviewed and approved by government prior to the start of construction.

Toxic Substances and Air Emissions

22. It is recommended that Esso prepare contingency plans for handling, storage, transportation and disposal of all toxic and hazardous materials and that such plans be in place prior to the commencement of the project.

23. It is recommended that Esso commence a monitoring program for ground level concentrations of air emissions in the Norman Wells area and that this monitoring continue throughout the life of the project.

Water Use and Effluent Disposal

24. It is recommended that no drilling wastes other than mixtures of water and bentonite be allowed to enter the Mackenzie River and that land disposal and treatment sites be identified and developed.

Archaeology

25. It is recommended that the responsible Federal and GNWT agencies further review the details of IPL's proposed archaeological program, and monitor the potential impact of this project on the archaeological resources along the pipeline route.

Environmental Impact Management

26. It is recommended that, in consultation with the GNWT, the Department of Environment, DIAND or a contracted non-government agency carry out an evaluation of the impact management process in order to improve on impact evaluation and mitigation on the Norman Wells and future projects.

27. It is recommended that the GNWT and Federal Government work with the Proponents to establish an effective and ongoing public information program to respond to concerns of Mackenzie Valley residents.

APPENDIX D

ENVIRONMENTAL AGREEMENT

BETWEEN

INTERPROVINCIAL PIPE LINE (NW) LTD.

AND THE

DEPARTMENT OF INDIAN AND NORTHERN AFFAIRS

SEPTEMBER 1982

Environmental Agreement: Norman Wells Pipeline

This Agreement made this 28th day of September, A.D. 1982.

BETWEEN: Her Majesty the Queen in Right of Canada represented herein by the Minister of Indian Affairs and Northern Development, hereinafter called "Her Majesty"

OF THE FIRST PART

AND: Interprovincial Pipe Line (NW) Ltd., a company incorporated under the Canada Business Corporations Act, having its registered office in the City of Edmonton, in the Province of Alberta, hereinafter called "the Company"

OF THE SECOND PART

WHEREAS the Company wishes to construct and operate a pipeline and related works (hereinafter called "the Works") from Norman Wells, Northwest Territories to the Alberta-Northwest Territories border;

AND WHEREAS approval has been given for the construction, operation and maintenance of the Works by the Company conditional on the Company meeting all applicable regulatory requirements and conditions pertaining to such construction, operation and maintenance;

AND WHEREAS the Company has submitted to the Minister of Indian Affairs and Northern Development (hereinafter called "the Minister") an Environmental Impact Statement designed to identify significant environmental impacts and measures designed to mitigate potentially adverse impacts;

AND WHEREAS a Federal Environmental Assessment and Review Panel has reviewed the Environmental Impact Statement and has held public hearings and made recommendations on methods of minimizing the said environmental impacts which may arise from the construction, operation and maintenance of the Works;

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AND WHEREAS the Minister wishes to ensure that the principle of minimum practicable environmental and land use disturbance shall apply to the planning, design, construction, operation, maintenance and abandonment or removal of the said Works;

AND WHEREAS the Minister has appointed a Project Coordinator who is charged with coordinating the Minister's responsibility for the regulation and management of the construction, operation, and maintenance of the Works, and assisting the Company, on a timely basis, in obtaining all approvals necessary in relation thereto.

NOW THEREFORE THIS AGREEMENT WITNESSETH that in consideration of the mutual covenants and agreements herein contained, the parties hereto agree as follows:

1. Where the Minister is of the opinion that the construction or operation of the Works has caused or is likely to cause a significant adverse environmental impact, the Company agrees to take such measures as are satisfactory to the Minister to prevent, mitigate or remedy the said impact and to prevent its recurrence.

2. The Company agrees to cooperate with the Minister in the development and implementation, by the Minister, of a monitoring program designed to:

(a) facilitate an evaluation of the impact management process in order to improve on impact evaluation and mitigation on the Norman Wells Pipeline and future projects.

(b) facilitate an assessment of the effectiveness of regulation of the construction and operation of the Works.

3. Where the Company is required, pursuant to a specific regulatory approval or approvals, to develop and implement monitoring programs designed to detect and assess significant environmental

change resulting from the construction and operation of the Works, the Company agrees to develop and implement such programs.

4. The Company agrees, during the construction, operation and maintenance of the Works, to protect, to the maximum extent practicable, inland waters against the adverse effects of siltation caused by such construction or operation, and spills of fuel and toxic chemicals.

5. The Company agrees to construct, operate, and maintain all structures placed in inland waters in a manner suitable to the hydrologic and hydraulic conditions of the said waters.

6. The Company agrees to develop and implement, to the satisfaction of the Minister, during construction of the Works and in relation to such construction, environmental training programs, which shall emphasize principles of prevention of environmental damage, and the development of prompt, appropriate action required to be taken during emergency situations which may cause damage to the environment.

7. In permafrost areas, in addition to the "permafrost measures" undertaken for engineering purposes, the Company agrees as soon as practicable after construction of the Works or any portion thereof, to implement, to the satisfaction of the Minister, measures designed to prevent or reduce significant adverse environmental impacts arising from the thawing or build-up of frozen ground. Such measures will be designed to prevent or reduce, inter alia, detrimental effects on water quality, fish, wildlife, vegetation, and terrain stability arising from ground surface degradation (thermokarst), slope failure, instability of stream banks, ponding, changes in surface drainage pattern, changes in groundwater movement including flow through river-bed gravels, and build up of frost bulbs or icings.

...4

8. The Company agrees to provide and maintain adequate erosion controls to the satisfaction of the Minister, on all lands used in connection with the construction and operation of the Works, designed to minimize, inter alia, the disturbance of natural drainage, accelerated erosion and any increase in the normal sedimentation process into inland waters.

9. The Company agrees to obtain the prior approval of the Minister as to the location of solid waste disposal sites, and as to the type of waste which may be deposited at such sites.

10. The Company agrees to take all reasonable precautions to prevent any fire occurring or spreading on the lands used in connection with the construction, operation and maintenance of the Works, and will pay all costs of suppressing or containing any fire which is caused by or attributable to the activities of the Company, its employees, workers, agents, contractors and sub-contractors in connection with such construction, operation and maintenance.

11. The Company agrees to develop and maintain for the construction, operation and maintenance of the Works appropriate emergency procedures, satisfactory to the Minister, for hydrocarbon spills and forest fires.

12. Upon the expiration or termination of this Agreement, the Company agrees to deliver up possession of the land used in connection with the construction, operation and maintenance of the Works in a restored condition in accordance to the plan approved pursuant to section 13.

13. (1) The Company agrees, within four years from the date of execution of this Agreement, to deliver to the Minister for his review and approval a plan of restoration which, where applicable, shall include but is not limited to, provisions for:

(a) the removal of buildings and other structures;

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(b) the disposition of roadways;

(c) the disposition of water supply facilities;

(d) the reclamation of petroleum and chemical storage or disposal sites and facilities;

(e) the reclamation of garbage, sewage and waste storage and disposal sites and facilities;

(f) the disposition of pipelines;

(g) the reclamation of site drainage systems;

(h) the disposition of all other facilities utilized for the project;

(i) the reclamation of the surface of lands used for the project generally; and

(j) the timing of such activities.

(2) The plan referred to in subsection 1 shall be prepared with the objective of restoring the land used in connection with the construction, operation and maintenance of the Works as near as reasonably possible to its original state or leaving the land in a re-usable condition in keeping with the natural surroundings and abutting land use.

14. (1) Upon receipt of the plan required pursuant to section 13, the Minister shall:

(a) approve the plan as submitted;

(b) reject the plan in whole or in part; or

(c) require the addition of such provisions that, in his opinion, are required to meet the objective described in subsection 13(2).

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(2) The Minister shall, within six (6) months of receipt of the said plan, advise the Company, in writing, of his decision made pursuant to subsection (1) stating, where applicable, his reasons for rejection or amendment.

(3) The Company shall, within six (6) months of receipt of the Minister's decision made pursuant to subsection (1), deliver to the Minister for approval a revised plan of restoration containing such changes as are required by the Minister pursuant to the said subsection (1).

(4) The Company agrees to submit, two years prior to the termination of this Agreement, a current updated plan of restoration containing the provisions outlined in subsection 13(1). Section 13 and subsections 14(1) to (3) shall apply mutatis mutandis to the submission of the plan as required by this subsection.

15. Where the Company fails to carry out the requirements specified in sections 12, 13 and 14, the Minister, with the concurrence of the National Energy Board, may carry out or cause to be carried out any restoration which he deems necessary with respect to all or part of the area and any expenses thus incurred by the Minister shall be recoverable from the Company as a debt due to the Crown.

16. The Company agrees that its contractors and sub-contractors will be required to comply with the provisions of this Agreement as they pertain to the activities of contractors and sub-contractors.

17. The parties acknowledge that the Company may require land use and quarry permits issued pursuant to the Territorial Lands Act and regulations made thereunder, and water authorizations or licences, issued pursuant to the Northern Inland Waters Act and regulations made thereunder. Where such permits, authorizations or licences contain terms and conditions which conflict with this Agreement, those terms and conditions shall prevail.

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18. Wherever, pursuant to this Agreement, provision is made for the Minister to give his approval as to the activities or proposed activities of the Company, and where, in any case, such approval is refused by the Minister, the Company may request that the Minister review his decision to refuse approval, and the Minister shall carry out such review. For this purpose, the Company may make representations to the Minister in order to assist the Minister in carrying out such review.

19. Nothing in this Agreement shall be interpreted as limiting the right of the Company to carry on its business in accordance with good management practices and all applicable laws.

20. For greater certainty, the parties acknowledge that, notwithstanding anything herein contained, the Company is, and will be subject to and bound by, the Territorial Lands Act and regulations made thereunder and the National Energy Board Act and regulations made thereunder, all as amended from time to time, where the said Acts and regulations are applicable to the activities of the Company, and the Company covenants and agrees, in respect of the lands used in connection with the construction, operation and maintenance of the Works, to comply with and be bound by those statutes and those regulations.

21. If at any time during the continuance of this Agreement the parties hereto shall deem it necessary to make any alteration or addition to this Agreement, they may do so by means of a written agreement between them which shall be supplemental hereto and form part hereof.

22. This Agreement shall be binding upon and shall enure to the benefit of Her Majesty and Her Successors and the Company and its successors and assigns.

23. The Minister and the Company will direct their representatives to meet at least annually to review activities of the parties in respect of this Agreement.

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24. Nothing herein will prejudice Her Majesty's or the Company's right to any right or remedy with respect to a breach of any covenant or agreement contained in this Agreement.

25. Unless a waiver is given in writing by the Minister or any person authorized by him, Her Majesty will not be deemed to have waived any breach by the Company of any of the covenants or agreements herein contained, and any waiver shall relate only to the specific breach to which it refers.

26. If the parties hereto cannot agree on the interpretation of this Agreement or any part hereof, or any question of fact, law, or mixed fact and law arising herefrom, the same shall be submitted to, and determined by, the Federal Court of Canada.

27. All notices to be given hereunder shall be in writing and may be served personally or by registered letter addressed to Her Majesty at:

Department of Indian Affairs and
Northern Development,
Les Terrasses de la Chaudière,
North Tower,
OTTAWA, Ontario K1A 0H4

Attention: Assistant Deputy Minister,
Northern Affairs Program

and to the Company at:

The Project Manager,
Norman Wells Pipe Line Project,
Interprovincial Pipe Line (NW) Ltd.,
The Interprovincial Pipe Line Tower,
10201 Jasper Avenue,
P.O. Box 398,
EDMONTON, Alberta T5J 2J9

with a copy to:

The Secretary,
Interprovincial Pipe Line (NW) Ltd.,
P.O. Box 48,
1 First Canadian Place,
TORONTO, Ontario M5X 1A9

or such other address, in either case, as Her Majesty or the Company respectively may from time to time advise, and any such notice shall be deemed to be given to and received by the addresses upon personal

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service or, if served by registered letter, fourteen (14) days after the mailing thereof, postage prepaid.

28. No member of the House of Commons shall be admitted to any share or part of this Agreement or to any benefits to arise herefrom.

29. This Agreement shall commence on the date of execution and shall continue until the easement or easements, granted by Her Majesty by Letters Patent, for the construction and operation of the Works, is or are terminated, or surrendered, or until the Works are abandoned or removed, whichever occurs first, unless otherwise agreed to by the parties.

IN WITNESS WHEREOF the Minister of Indian Affairs and Northern Development has hereunto set his hand and seal on behalf of Her Majesty the Queen in Right of Canada and the Company has hereunto affixed its corporate seal attested to by its proper officers fully authorized on that behalf.

Signed, Sealed and Delivered by the Minister of Indian Affairs and Northern Development in the presence of)

Witness

Minister of Indian Affairs and Northern Development

Sealed, Attested To and Delivered by) Interprovincial Pipe Line (NW) Ltd.

by: Treasurer and Director

by: Corporate Secretary

APPENDIX E

REPORTS BASED ON THE NORMAN WELLS PIPELINE PERMAFROST AND TERRAIN RESEARCH AND MONITORING PROGRAM

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